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AN ANALYSIS OF CONCEPTUAL SOLUTIONS FOR SEA STATE 3 RO/RO DISCHARGE FACILITY OPERATIONS

SEPTEMBER 1989

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This report presents the results of the parametric analysis conducted to rank conceptual solutions for RO/RO Discharge Facility operation through the range of Sea State 3. The analysis was a systematic approach to a quantitative comparison of the concepts. The study consisted of numerical seakeeping analyses, identification of a hierarchy of platform design and operational parameters, and a weighted analysis to rank the concepts. In addition to the parametric analysis, ship-to-shore operational problems are identified and some conceptual solutions are developed. Conclusions and recommendations for further development are also offered.

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1.0 INTRODUCTION

A vital link in the Navy Strategic Sealift Program is the logistics support for sustaining a major amphibious assault operation. A significant portion of the cargo to be transferred during the logistics support effort would be carried via Roll-On/Roll-Off (RO/RO) ships. It is imperative that the capability exist to offload this cargo in an area where port facilities may be unusable or even nonexistent. The RO/RO Discharge Facility (RRDF) is the principal mechanism for accomplishing this task by providing an interface platform between the RO/RO ship and lighterage which will shuttle vehicles ashore. The historical background and a complete description of the RRDF development process can be found in Reference 1.

The RRDF consists of a Causeway Platform Facility (CPF), an optional 120 foot portable calm-water ramp (CWR) for use with ship's not having a ramp, and causeway ferries propelled by a powered causeway section (CSP). The CPF is a floating platform made up of six of the U.S. Navy's Navy Lightered (NL) P-Series pontoon non-powered causeway sections (CSNP); each section is roughly 90 feet long, 21 feet wide, and 5 feet deep. The sections are joined together in a "three wide-by-two long" configuration using a flexor and shear connector system to construct a platform with an approximate overall length of 180 feet and width of 65 feet. The flexor connector allows rotation of up to 15 degrees about the horizontal axis while restricting horizontal displacement. The shear connector prevents vertical and longitudinal displacement. Each causeway section has a pair of flexor and shear connectors per end and side, thus allowing the platform to articulate in both roll and pitch. Typically, an additional causeway section, commonly known as a "B" or "offshore" section, extends outward from the center section of the CPF.

The outboard end of the "B" section is sloped and has a "rhino" horn which provides an attachment point for the bow ramp of a Landing Craft Utility (LCU). The intersection of the "B" section and the CPF forms a convenient "L" shaped mooring location for a causeway ferry. The CPF and the "B" section provide a platform for the transition of wheeled and tracked vehicles from the RO/RO ship to the waiting lighterage (causeway ferries or LCUs).

RO/RO vessels using the RRDF may be self-sustaining (SS RO/RO), with an integral ship's ramp, or a non self-sustaining (NSS RO/RO), dependent on the CWR. The self-sustaining vessels have various kinds of ramp configurations: stern, quartering or side port. Non self-sustaining ships without integral ramps use the CWR and also can have various ramp arrangements. Figures 1 and 2 illustrate the RRDF moored alongside representative NSS RO/RO vessels. Figure 1 depicts a stern arrangement with two side loadable warping tugs (SLWT) moored alongside the CPF and a "B" section extending outward from the center of the CPF. Figure 2 depicts a side port discharge arrangement, one SLWT alongside the CPF, a "B" section extending outward and a causeway ferry powered by a SLWT moored to the "B" section and the CPF.

The success of the RRDF in discharging military vehicles has been demonstrated in calm water and in a nominal Sea State 2. The results of these exercises are documented in References 2 through 6. In its current design configuration, the RRDF is incapable of being operated when the seas build to a 3 to 5 foot significant height, generally defined as Sea State 3. The inability to discharge vehicles in a seaway such as this is due to the CPF's motions and the relative motion between the ship's ramp and the CPF. Unacceptable CPF motions cause deck wetness in the form of either green water or spray which makes vehicle and personnel movements hazardous. In very cold environments this could lead to icing on the deck which would further exacerbate the problems.

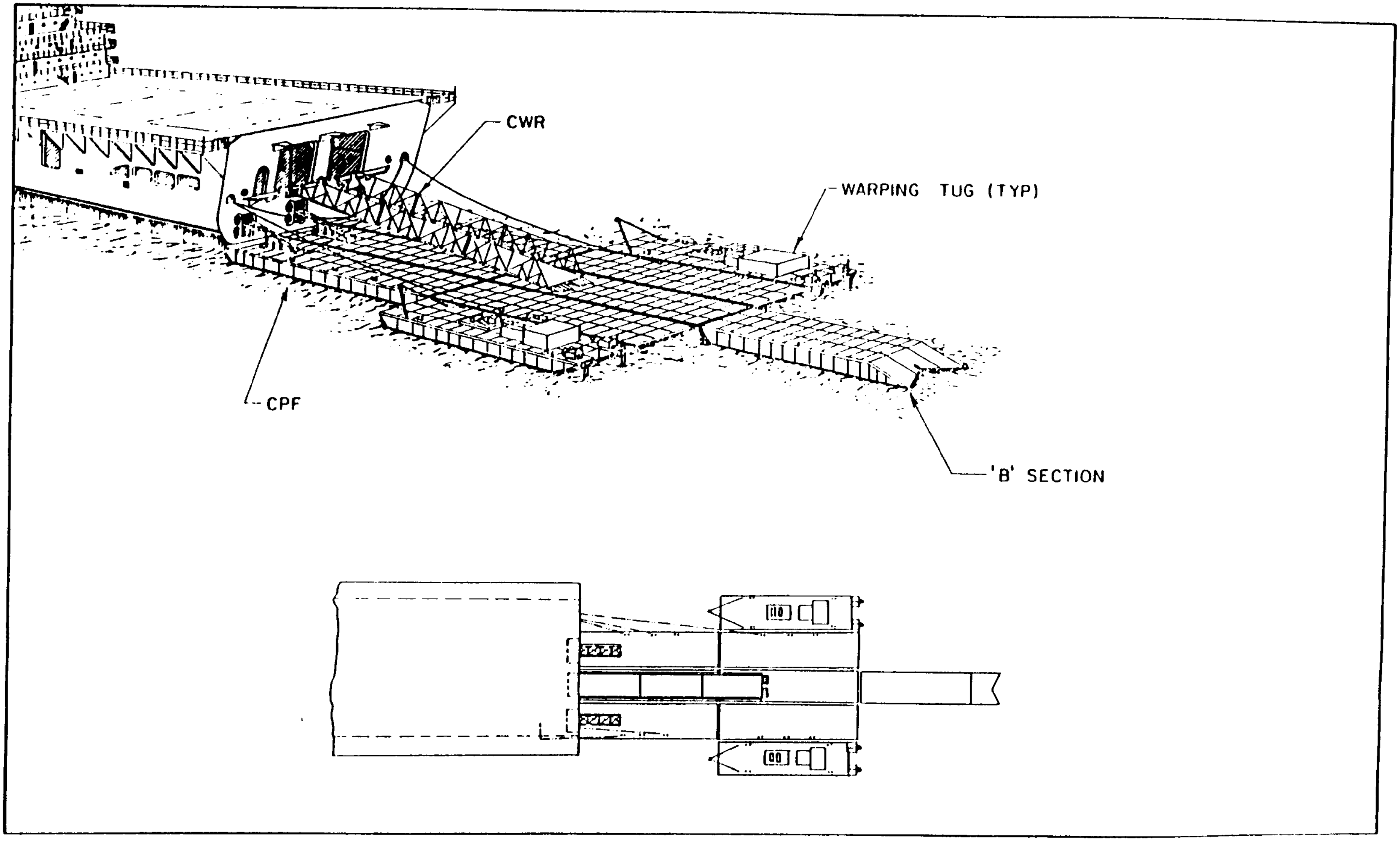


Figure 1 RRDF Moored Astern RO/RO Vessel

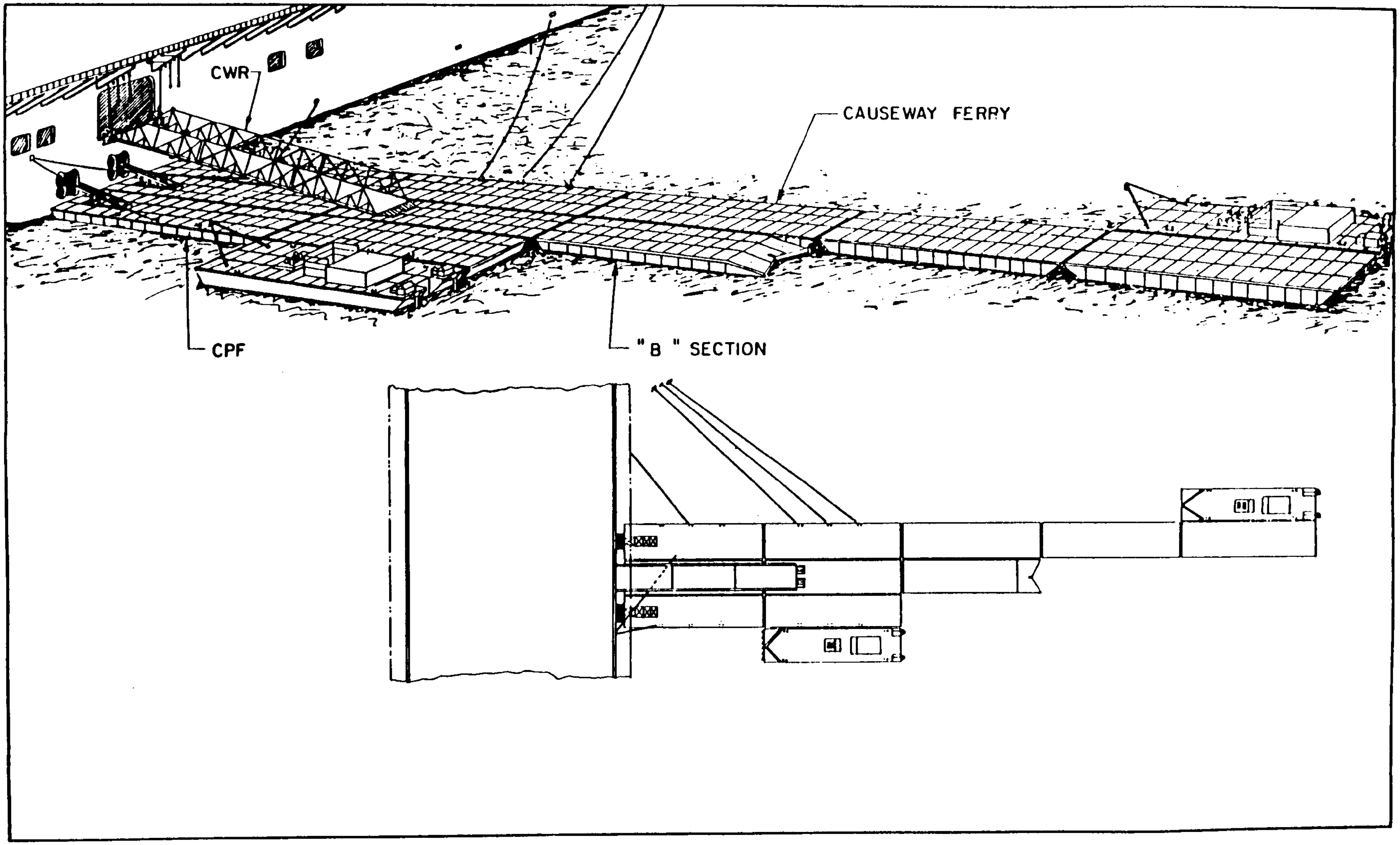


Figure 2 RRDF Moored Alongside RO/RO Vessel

Relative motions between the CPF and the RO/RO vessel can contribute to the generation of excessive forces and moments on the ramp. Since the outboard end of the ramp rests on the platform under its weight alone, relative motions can cause the ramp to pivot about one corner (i.e. one corner remains resting on the platform while the other corner becomes separated). Vehicles being driven over a ramp which is tending to pivot in this manner would generate torsional loads within the ramp which may exceed structural limits.

Since it is very unlikely that an amphibious assault landing operation will occur during benign weather conditions, there is a definite need to develop an offloading capability in higher sea states. Various concepts have been developed for RRDF offloading operation through the range of Sea State 3 and are described in Reference 7. These concepts include modifying the arrangement of existing hardware, using other available or recently developed hardware, and developing totally new hardware. The concepts which utilize modifications of the arrangement of existing hardware include enlarging the CPF by adding causeway sections or using an alternate combination of rigidly and flexor connected causeway sections. The concepts requiring the use of other available or recently developed hardware include installing roll damping devices on the outboard edges of the CPF, replacing the existing CPF design with a large sealift-type barge, constructing the CPF as one or more large barges using NA pontoons as the basic building block, or using propellant embedded anchors to moor the CPF. The concepts requiring the development of new hardware include a reduced waterplane area causeway section to minimize wave-induced motions and the use of hydraulically damped CPF-to-ramp interface which would reduce potentially excessive torsional loads in the ramp.

Advanced Marine Enterprises, Inc. (AME) was tasked by the David Taylor Research Center (DTRC) under contract number N00167-86-D-0069 to evaluate these concepts. This report presents the results of the parametric analysis that was conducted to rank these concepts. This analysis was a systematic approach to a quantitative comparison of the various options and concepts. The study consisted of numerical seakeeping analyses to investigate the absolute and relative motions of the various configurations, identification of a hierarchy of platform design and operational parameters, and a weighted analysis to rank the various concepts. In addition to this parametric analysis, ship-to-shore operational problems are identified and some conceptual solutions are developed. Conclusions and recommendations for further development are also offered.

2.0 DESCRIPTION OF CONCEPTS FOR SEA STATE 3 RRDF OPERATIONS

Several concepts have been developed to permit safe RRDF offloading operation through the range of Sea State 3. In some cases these concepts utilize existing hardware. In others, new hardware or innovative application techniques are required. All of the concepts which have been developed are briefly described in the following sub-sections. Some of the concepts were not considered in this detailed analysis and the logic for that decision is provided. Other concepts were not necessarily germane to this analysis technique but do merit further consideration.

2.1 Concepts Considered in this Analysis

2.1.1 Sealift Barge

During the past twenty years several developments have resulted in an increase in the number of commercial sea transports of large equipment and structures on barges. Major oilfield developments in remote areas such as the North Slope of Alaska have required that the process modules be transported to the site from areas where adequate manufacturing exists. Offshore oil drilling platform jackets are typically towed on a barge to the drilling site and launched by ballasting one end of the transport barge. The barges used in these various sealift operations typically have a length of about 400 feet, a beam of about 100 feet and a range of displacement from about 5000 to 8000 long tons (LT).

A commercially available barge such as this could be used to replace the CPF. A barge of this type would significantly increase the size of the RRDF. There are numerous logistical options associated with using a barge of this type. As a minimum, the barge must have a self-contained ballasting system to allow adjustment of the freeboard of the RRDF in order to properly mate with the lighterage in use at the time. The barge could even be semi-submersible for transporting tugs to the offload site. Another alternative would be to have the barge prepositioned which would minimize the transit time.

For the purposes of this analysis, the barge considered has a length of 400 feet, a beam of 100 feet, and a draft of 10 feet. Figure 3 illustrates a CAPE H (HORN, HENRY, HUDSON) Class RO/RO vessel with a barge of this size in a stand-off moor.

2.1.2 Partially Articulated Causeway Platform

The rationale behind the development of this concept is to potentially reduce the relative motion between each section of the CPF by modifying the articulation of the platform. The overall dimensions of the CPF would remain the same size as the baseline configuration. The articulation would be modified so that two rigid sections, 65 feet by 90 feet, would be connected using a "flexor hinge". The 65 by 90 foot section would be made up of three standard CSNP sections with side connectors modified to be rigid instead of the current flexor connectors. The rigid side connectors would require some development. The connectors between the two 65 by 90 foot sections would remain as presently designed, thereby creating a "flexor hinge" at the end-to-end connection. This configuration should result in reduced relative motion across most of the platform. The arrangement of this configuration is illustrated in Figure 4.

2.1.3 CPF with Additional Sections

This configuration would be developed by modifying the existing CPF by adding similar causeway sections to increase the size of the platform and potentially develop a lee for the transfer portion of the platform. The concept would be to attempt to attenuate some wave energy through the hinges

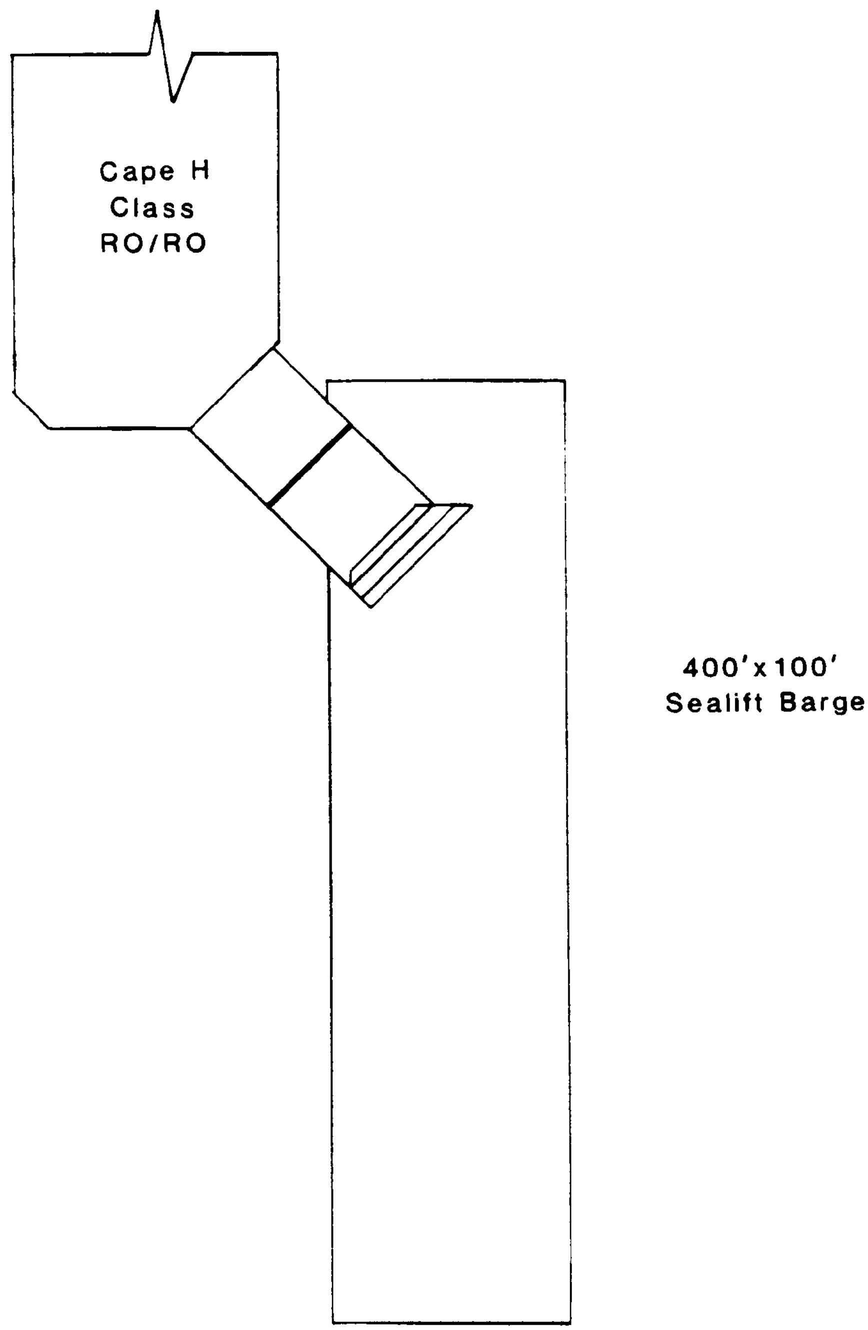


Figure 3 Cape H Class RO/RO with Sealift Barge

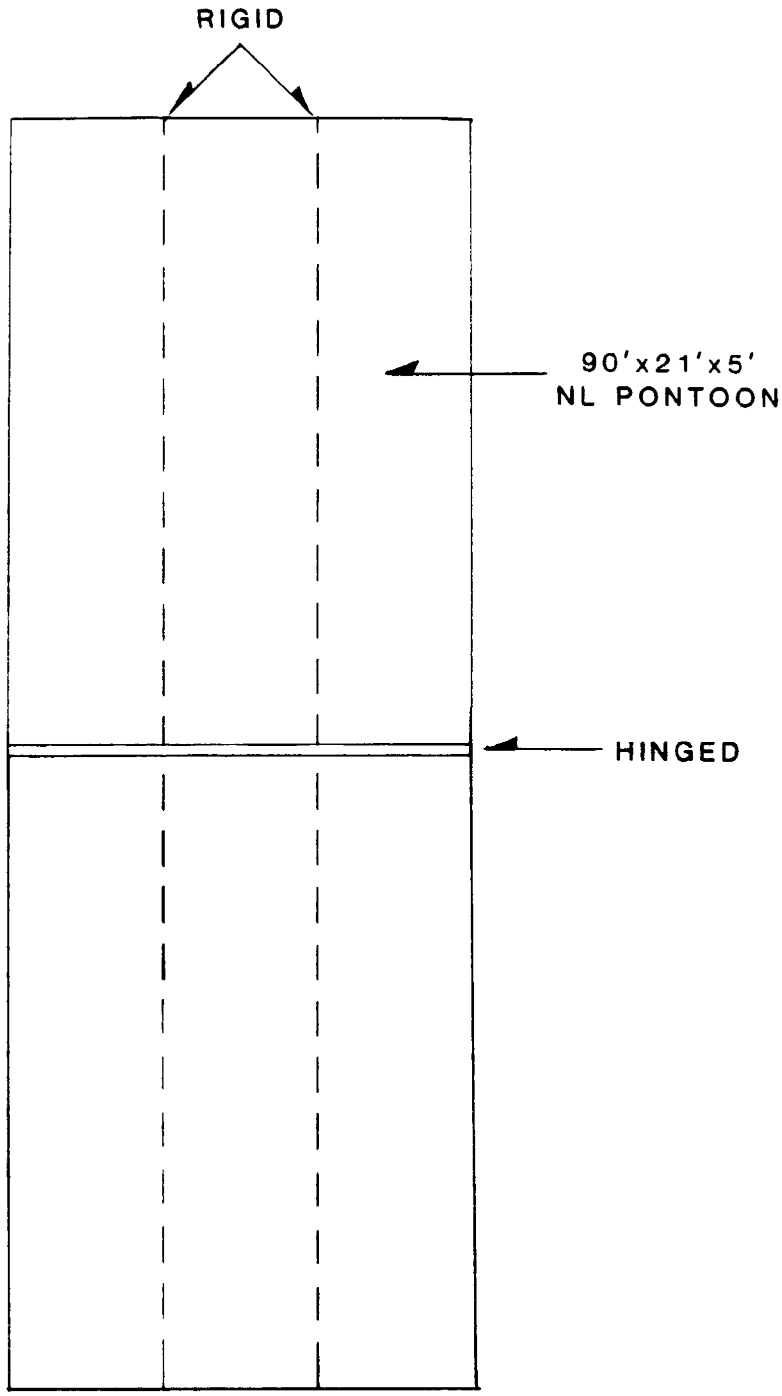


Figure 4 Arrangement of Partially Articulated CPF

connecting the additional sections. In principle, this would reduce the motions of the transfer portion of the platform. All hardware for this concept is currently available. Figure 5 illustrates the configuration of this concept used in this analysis.

2.1.4 Causeway Sections Using Navy-Army (NA) Pontoons

The basic building block in this concept is the ISO compatible NA pontoon. This platform would be configured with rigid side-to-side connectors and flexible end-to-end connectors. Use of the NA pontoon as a basic building block for CPF will allow assembly of various sizes of platforms. Two major features distinguishing the NA pontoon platform from the NL platform are:

o The NA pontoon is ISO compatible, and therefore much easier to transport and handle than the existing NL CSNP causeway .

o The rigid intercell connectors used on the NA pontoons eliminate the flexibility that is inherent in the flexor connectors and shear connectors used for side-to-side and end-to-end connection of the CSNP causeways.

The large, rigid platforms that are achievable with NA pontoons offer the possibility of improved stability in a seaway due to their larger rigid mass and their larger area. However, in swells, this may not necessarily be the case. A possible solution may be to use the NA pontoons to make platforms of different sizes with varying conditions. Side flexors would be designed for the pontoons also. For example, in regions of the world where the waves are typically short and steep, the platform could be made up of solid, wider sections. In other areas, where the waves are typically longer swells, the platform could be made up of multiple short narrow sections. Figure 6 illustrates the arrangement of this concept. This analysis assumed

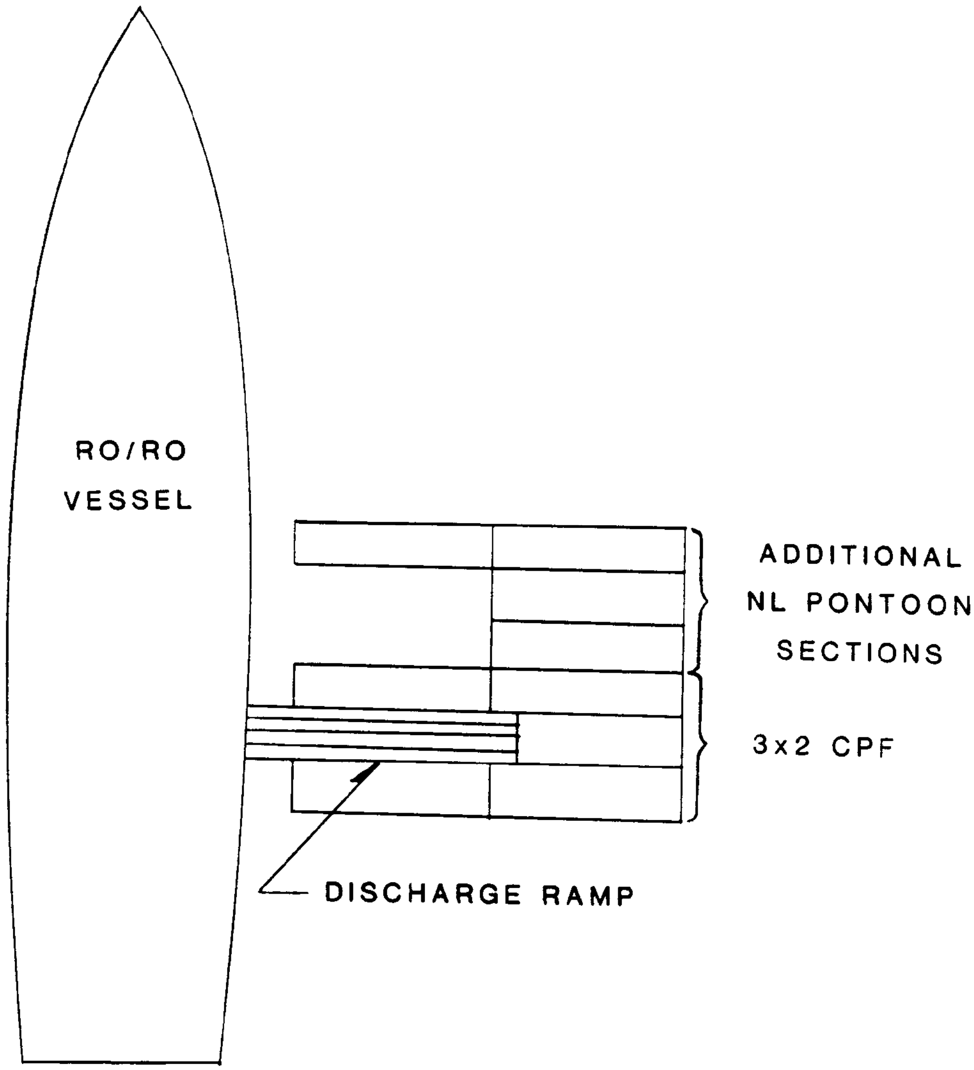


Figure 5 CPF with Additional Sections

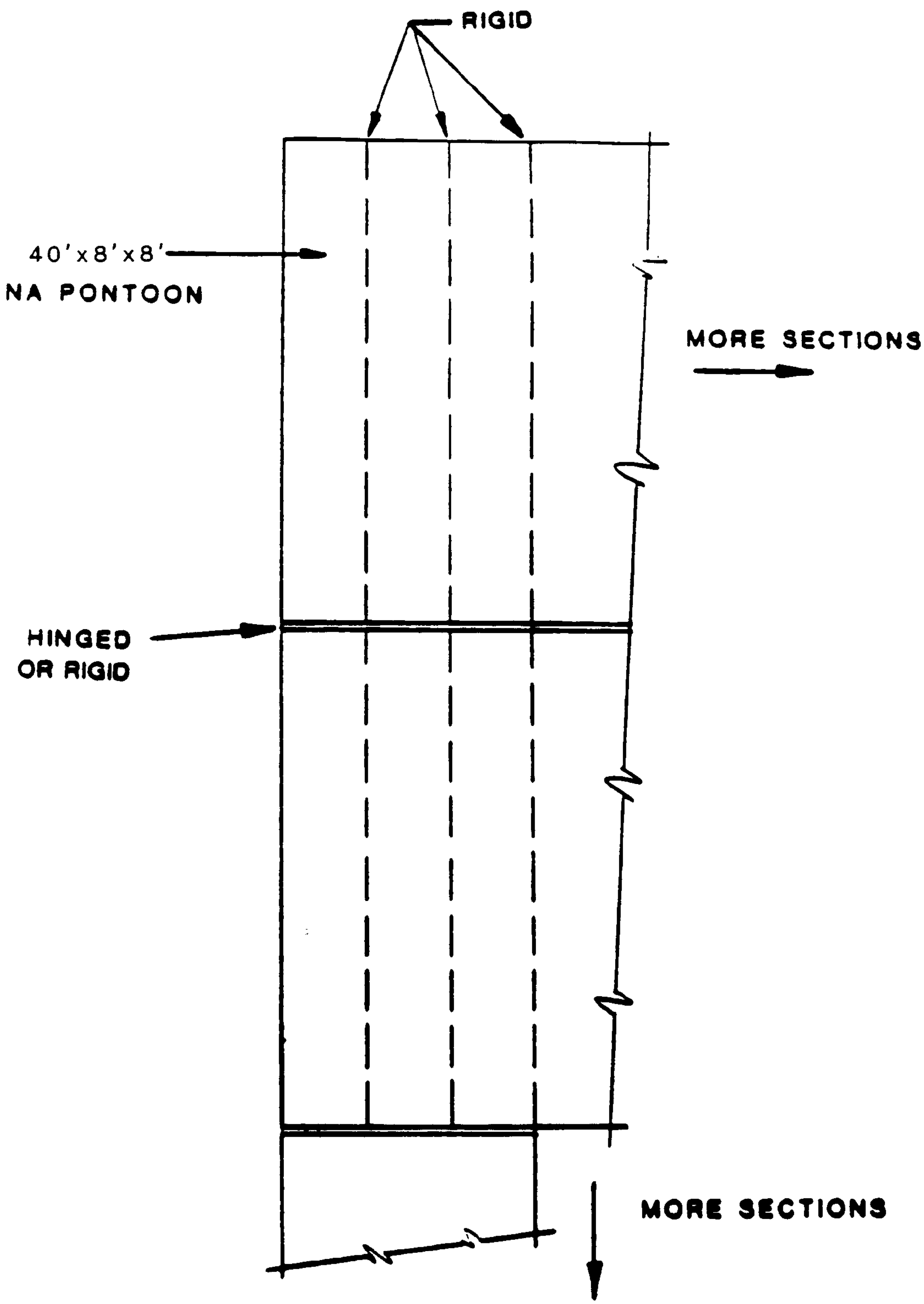


Figure 6 Arrangement of CPF with NA Pontoons

that the rigid/flexible connections could be designed to be structurally adequate in Sea State 3.

2.1.5 Use of Roll Damping Devices on Baseline CPF

This concept would employ the use of motion damping devices to reduce the amplitude of motion of each individual causeway section. In this analysis, the baseline CPF is considered with a series of motion damping devices attached along the outboard edges of the platform. The development of these "flopper-stoppers" type of roll damping devices, has been an empirical process which has evolved over the years using quite a bit of "seaman's eye" and little formal engineering. In its simplest form, the system consisted of a flat steel plate supported by a three part bridle. If the system failed during use it was simply repaired and strengthened and from a trial-and-error system a new design would evolve. Prior to 1976 there is little evidence of formal engineering used in the design process and the measure of effectiveness was typically a purely personal reaction. Reference 8 documents some full-scale measurements of forces, roll angles, and sea conditions while flopper stoppers were deployed from the research vessel CAPE HENLOPEN.

Reference 9 is a second generation design methodology which evolved following the trials documented in Reference 8. The methodology deals with an evolved form of a flopper stopper, a paravane stabilizer, however it is not directed toward the detail design of the paravane but rather toward selecting the required size of the wing area. The size is determined by the amount of damping required to achieve a specified percentage of roll reduction.

Paravane stabilizers evolved on fishing boats usually operating at some forward speed. A torpedo weapon recovery vessel, U.S.S. Crayfish deployed a roll damping system for use at zero speed. The design of this system is given in Reference 10 and is the basis for the concept for use on the CPF.

The size of the dampers required to reduce the roll motion of each causeway section by 50% was calculated using the methodology given in Reference 9. Figure 7 illustrates a possible configuration of this concept.

2.1.6 Summary of Principal Particulars of Concepts Considered in this Analysis

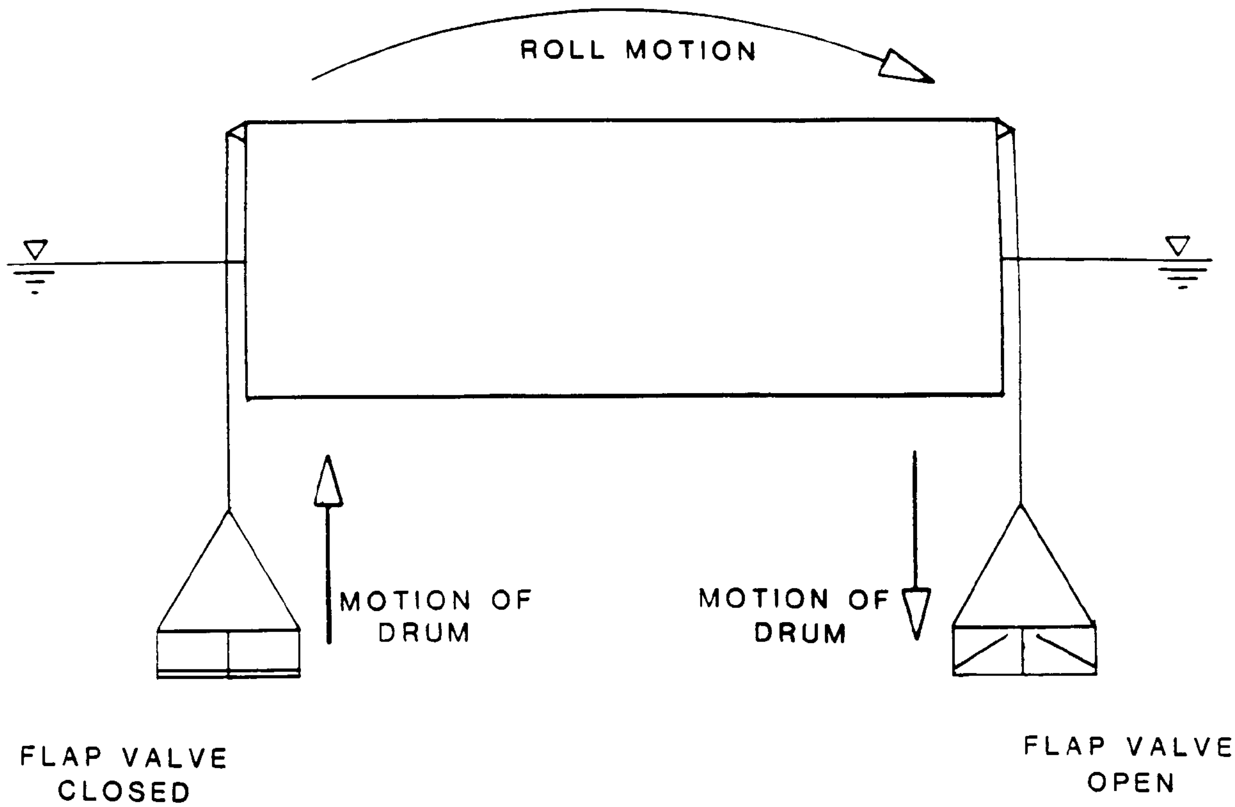
Five options for Sea State 3 RRDF operations are considered in detail in this analysis. Table 2-1 summarizes the overall geometric characteristics of each concept.

Table 2-1

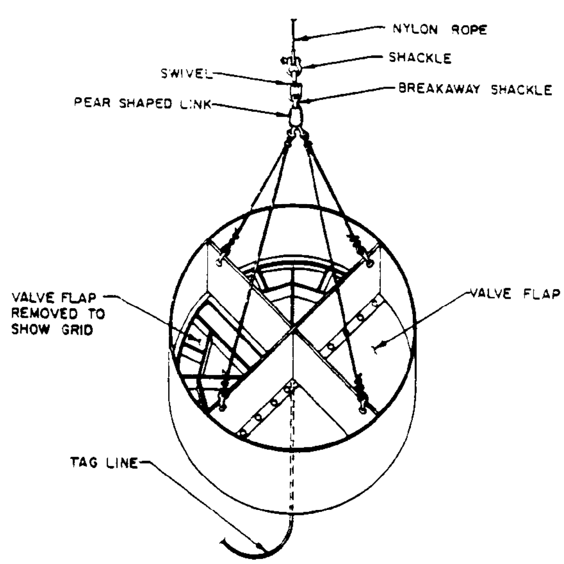
Summary of Principal Particulars of Concepts Considered in this Analysis

	SEALIFT BARGE CPF	PARTIALLY ARTICULATED CPF	ADDITIONAL SECTION CPF	NA PONTOON CPF	ROLL DAMPED CPF
LENGTH OVERALL (FT)	400	180	180	160	180
BREADTH OVERALL (FT)	100	65	130	72	65
AVERAGE DRAFT (FT)	10.0	1.41	1.41	1.32	1.41(*)
INDIVIDUAL MODULE LENGTH/ BREADTH	400/100	90/65	90/20	72/40	90/20

(*) This value is the draft of the CPF only. Roll dampers would extend at least 10 feet below the baseline of the CPF.



a) Conceptual Arrangement of Dampers



b) Conceptual Design of a Damper

Figure 7 Roll Damping Concept for CPF

2.1.7 Multi-Point Mooring

A multi-point mooring capability could conceivably allow optimum ship positioning for offloading operations either by creating a lee for the RRDF or by positioning the RRDF in an orientation to the environment resulting in minimal motions and deck wetnesses. The moorings could be set in advance by auxiliary craft or provided as part of the RO/RO ship equipage and set by a SLWT. The moorings would be set in a pattern to allow the ship to shift within the moor to achieve optimum positioning. Ideally, the ship should have the self-contained ability, using integral winches, to shift within the moor due to changing wind or wave headings.

This concept is not considered independently from the previously mentioned concepts. Rather, it is considered applicable for each concept and the motion analyses will address the effect of heading relative to the environment. An issue that will not be addressed is the cost or necessity of providing each RO/RO ship with the capability to shift herself within a multi-point moor.

2.2 Concepts Not Considered in this Analysis

Some concepts which were proposed in Reference 7 were not considered in full detail during this analysis for a variety of reasons. The following sub-sections describe these concepts and provide the rationale for not including them in this analysis.

2.2.1 Reduced Waterplane Area Platform

The reduced waterplane area hull concept has been used successfully to improve the seakeeping characteristics of small ships and semi-submersible oil drilling platforms. For a ship, the common term to describe this concept is SWATH, Small Waterplane Area Twin Hull. The reduced waterplane area alters the response characteristics of the vessel to incoming wave energy by shifting the natural periods of response away from the ranges of periods of the waves. Typical natural periods in pitch and roll for a SWATH vessel or a semi-submersible rig would fall in the range of 20-24 seconds while most of the wave energy in the ocean lies in the ranges of 3-14 seconds.

To develop a CPF using this concept would require totally new hardware. Either individual sections would have to be designed to be compatible with existing transfer techniques or a single large platform would be designed and the transfer technique would be modified. A new transfer technique would require the use of alternate ship type for transfer, such as a SEABEE or a semi-submersible ship or barge. The level of complexity and prohibitive cost involved in designing a new section or platform and requiring an alteration of the transfer process contributed greatly to eliminating this concept from further consideration.

The reduced waterplane area which greatly improves the response of a vessel to incident wave energy is also a limiting factor in its application to cargo transfer. The low waterplane moment of inertia which shifts the response natural periods away from the incident wave energy periods also makes the vessel very sensitive to weight shifts. An RRDF which will have very heavy vehicles traversing from side-to-side cannot be very sensitive to weight shifts. For this reason also, this concept was eliminated from further consideration.

2.2.2 Tensioned-Leg Platform

The offshore oil industry is using the tensioned-leg platform concept to explore for oil in water depths greater than 1500 feet. To apply this concept to the RRDF would require the use of electric drive constant tension winches on the platform to maintain a constant tension in the anchor cables and thus stabilize the platform. The anchoring system would require the use of either propellant embedded anchors or large gravity anchors. This concept would require a preselected position for the RRDF and an electrical power source for the winches; either from a "shore power" line, the discharging ship, or from a self contained diesel generator. An additional reason for eliminating this concept is that a large degree of stabilization would increase deck wetness.

Although this system is potentially usable with existing CPF hardware, its limitation include: the need to fix the position of the ship and the RRDF so that no adjustments to a changing environment are possible, the requirement for an electrical power source for the constant tension winches, and the need to use an anchoring system which requires additional resources. Propellant embedded anchors are limited in both their holding power and the bottom conditions in which they will hold. Large gravity anchors would require a small buoy tender for deployment and/or adjustment. The combination of these limitations and the expected costs excluded this concept from any further consideration.

2.3 Concepts Requiring Further Development and Consideration

Some of the concepts proposed in Reference 7 have not been considered in this analysis because they require further development or were not necessarily germane to this analysis technique. Unlike the concepts listed in Section 2.2, these concepts should be considered further, but perhaps in a different fashion than is treated herein.

2.3.1 Ramp-to-Platform Interface

An interface platform between the ship's ramp and the CPF could be developed to isolate the motions of the ramp from the CPF. This interface platform would be hydraulically damped in all six degrees of freedom. By eliminating the relative motion between the ramp and the CPF, the potentially excessive torsional loads that would be generated in the ramp as the seaway builds could be eliminated.

This concept would not improve the motion characteristics of the platform but would certainly improve the capability of the ramp to be used in a seaway. Platforms such as this are commonly used in motion simulation laboratories and their technology would need to be applied to the RRDF. Control system development and sizing of dampers would be required. The potential benefits are significant and this system should be considered seriously for further development. At this stage, the analysis of this concept is not germane to the quantitative analysis described in this report.

2.3.2 Combinations of Concepts

Any of these concepts can be combined with each other to form "hybrid" concepts. Since there are practically an infinite number of possibilities for combinations, they are not treated as such. However, in interpreting the results of this analysis, combinations of some of the more promising concepts should be considered.

3.0 MOTIONS ANALYSIS TECHNIQUES

In the comparison of various concepts for improving the operational capabilities of the RRDF in a seaway, the single most important parameter is the wave-induced motion of the platform. Other factors are important and contribute to the analysis but the motion of the platform is of primary concern. For this reason, the motion performance analysis will be treated first and foremost.

3.1 Overview of Motions Analysis

The motions performance analysis is designed to systematically compare the predicted motions that each of the concepts would experience in Sea State 3. This will be accomplished in a manner such that each concept will experience the same environment which will lead to an accurate "apple and apple" comparison.

Since the RRDF has been shown to be operational in Sea State 2 (References 2 through 6), the predicted motions of the baseline CPF in Sea State 2 will be used as a target. Each concept's predicted motions in Sea State 3 will be compared with the predicted motions of the baseline in Sea State 2. Ideally, the motions of a conceptual CPF in Sea State 3 should be equal to or less than the motions of the baseline in Sea State 2 in order for the concept to merit further consideration. The absolute motions of the CPF, deck wetness, and relative motions between the platform and ramp will be considered. Because of the size of the discharge ship and the relatively modest seaway which is dominated by fairly short wavelengths relative to the size of the ship, the motions of the ship will be considered negligible.

3.2 Numerical Methods for Motion Prediction

There are a number of analytical tools available for general seakeeping predictions which can be generally classified as either a two-dimensional strip theory program or a three-dimensional radiation/diffraction program. Most of the programs available have been thoroughly tested and validated, to a certain degree, against model or full-scale tests. Each program has its own set of inherent advantages or disadvantages for application and a brief description of four programs will follow.

The particular problem of predicting motions of the CPF in the presence of the offloading RO/RO vessel presents a hydrodynamic problem that is summarized by the following parameters:

- o A floating platform made up of multiple bodies with varying degrees of articulation,
- o Irregular waves with current and wind
- o Platform sections that are relatively small (in relation to incident wavelengths) in the presence of a large vessel, each one having a significantly different diffracting potential,
- o Varying degrees of hydrodynamic damping for each body,
- o Various mooring configurations between the articulated platform and the RO/RO vessel,
- o and finite water depths accounting for shallow water effects.

This list of physical constraints governing the problem necessitates a careful consideration of available tools for motion prediction.

3.2.1 Two-Dimensional Strip Theory

In this method of predicting wave-induced motions, the complex three-dimensional fluid flow problem presented by a floating body oscillating with six degrees of freedom is replaced by a rational summation of equivalent two-dimensional flow problems. The vessel is sliced transversely into some finite number of sections and each section shape is then represented with an equivalent two dimensional cylinder. The flow at any section is then considered to be independent of the flow at adjacent sections and the complexity of the problem is greatly reduced. The hydrostatic and dynamic forces are then computed for each section and the total force is calculated by integrating over the entire length of the vessel.

There are two very important assumptions in this theory which can be limiting factors in its application. First, the vessel is assumed to be wall-sided which means that its waterline does not change significantly as it heaves and pitches. For large displacement ships and the individual causeway section this assumption is reasonably valid. The other important assumption is that the transverse dimensions are small as compared to the longitudinal dimensions. This is typically known as the "slender body approximation". A general measure of the slenderness is the ratio of the waterline length to waterline beam. Typical merchant and naval ships have length to beam ratios of 6:1 to 10:1 while an individual causeway section's length to beam ratio is less than 4.5:1 and the CPF's length to beam ratio is less than 3:1. There is no distinct cut-off for the application of strip theory but this could be a limiting factor in its application towards calculating the motions of the CPF.

The US Navy's Ship Motion Program (SMP) is a two-dimensional strip theory program used widely throughout the naval architecture community for the prediction of ship motions in deep water irregular seas, either short crested or long crested. The program is fully documented in Reference 11. SMP calculates the Response Amplitude Operator (RAO) of the vessel's motion in all six degrees of freedom. Absolute motions, velocities and accelerations for various locations on the ship, and notional relative motion for specified points are all calculated in the frequency domain for various wave headings in 15 degree increments. Statistics of motions, slamming, deck submergence, and forefoot emergence are also provided in the output. All computations are made for a single body in a deep water seaway described by a Bretschneider spectrum. The limitation of only modelling a single floating body makes this program inappropriate for predicting the motions of the CPF.

Two other strip theory programs have been used to calculate motions of selected configurations of the RRDF. Causeway Train Motion (CATMO) was developed at NCEL and the results of previous calculations are documented in references 12 and 13. The program RELMO was developed for NAVFAC for predicting mooring forces, fender forces, and motion induced stresses in crane booms and other shipboard materials handling gear. Each of these programs employ a two-dimensional strip theory to calculate the hydrodynamic forces on each barge as if it were isolated while the connectors are modelled as a set of linear elastic beams. The results listed in References 12 and 13 are useful but are limited to deep water in a seaway described with a Pierson-Moskowitz spectrum, which is a fully developed sea in the open ocean.

3.2.2 Three-Dimensional Radiation/Diffraction Theory

A computationally more intensive approach to the problem of predicting wave-induced motions is to use a three-dimensional radiation/diffraction calculation scheme. In this technique, the radiation and diffraction analysis of wave action around the body is developed using the classical "Green's Function" approach. The body geometry is described by a mesh of panels and a pulsating fluid source is located on each panel. The combination of source strengths required to diffract an incoming wave of a given period while allowing body oscillation in each degree of freedom is then computed. The resultant calculation yields the diffraction force, added mass, and radiation damping. A more complete description of this technique is contained within Reference 14.

A suite of programs known as AQWA was developed using three-dimensional methods and has been primarily utilized in the offshore oil industry. The modules of AQWA are structured in a manner to allow calculation of the responses of multiple articulated bodies in both the frequency and the time domain. In the frequency domain, response amplitude operators are calculated in regular waves over a specified range of frequencies and motion statistics are computed in an irregular seaway. The description of the seaway is somewhat arbitrary and not limited to deep water or a single spectral definition. Time histories of response can also be calculated in regular and irregular waves. Articulation between the bodies can be modelled with variable mass and stiffness. Exact hydrodynamic interaction between the bodies is not calculated, however, the proper phasing of the relative motion between the bodies is calculated in regular waves and used to calculate statistics of motion in irregular waves.

The unique capabilities of the AQWA suite to model multiple articulated floating bodies in an arbitrarily-defined finite depth seaway, with the effects of mooring systems and hawser tensions considered, led to the selection of this tool for analysis. The modules used for this analysis were: AQWA-LINE, for geometry definition and calculation of basic hydrodynamic properties; AQWA-DRIFT, for calculation of the motion and load time histories of the articulated CPF in irregular seas; AQWA-FER, for calculation of motion statistics in irregular seas; and AQWA-PLANE, for graphic visualization of input body geometry and display of intermediate and final results.

3.3 Sea Spectral Description

In order to quantify the performance of any concept in a seaway, it is necessary to first establish the analytical description of the seaway. The baseline configuration of the RRDF has been shown to be operable into Sea State 2, loosely defined having a significant wave height of about 2 feet. Operational experiences have indicated that not only is the RRDF currently very sensitive to increasing wave height from the consideration of deck wetness but it is also very sensitive to increasing wave length, or the presence of swells, from the consideration of relative motion between the sections.

Numerous theoretical methods exist for idealized spectral description of a seaway and most are described in Reference 15. A point wave spectrum is simply a measure of the energy content in the sea from a given direction as a function of wave period or wave length. No directional information is available from a point spectrum description. The long crested wave assumption, which could adequately represent swells and is also commonly used as a "worst-case" basis, is that the wave energy is aligned with the wind direction. A few quantitative observations of directional seas have indicated that the wave energy is usually spread in a cosine-squared manner about the predominant direction. Although a spreading function such as this could be used, this analysis will only consider a long crested spectral description.

In most cases a sea state is referred to in terms of its significant wave height (average of the one-third highest waves) and modal period (i.e. period of peak energy content). The need to consider the effect of swells in the motion analysis precluded using only a single modal period spectral definition. For this analysis, a nominal Sea State 3 was desired with the inclusion of swells up to 17 seconds long. On an average annual basis, Sea State 3 can have a significant wave height of up to 4.6 feet and a most probable wave modal period of 7.5 seconds. Given the problem of including a 17 second swell with a freshly driven sea described by these parameters, an Ochi six parameter spectrum was selected to define the seaway for analyzing relative motion between the platform sections.

The unique features of the Ochi spectrum is that it allows the user to specify the severity of the sea, using a significant wave height, and a sharpness controlling parameter, emphasizing or diminishing the importance of selected frequencies. The development of the Ochi six parameter spectrum has two parts, one part for the primarily lower frequency components, modelling swells, and the other part for the higher frequency components, those from wind-generated seas. The spectrum of each part is expressed using the shape parameters, the significant wave height, and the modal frequency.

In a Sea State 3 description, an Ochi spectrum is heavily dominated by the swell component. This is very useful for examining motions on the platform sections but since the platform would tend to conform to the wave profiles in the longer waves, the relative motion between the platform and the water surface is practically zero. For examining deck wetness problems, this type of seaway description does not really provide any useful information. A Bretschneider spectrum is more practical for describing a freshly driven seaway for purposes of examining the deck wetness problem. References 4 and 6 contain environmental data which was used to develop a Bretschneider spectrum for deck wetness evaluations.

Figure 8 compares the two spectra that were selected for this analysis. It is interesting to note the distinct differences in the shapes of these spectra. Each has roughly the equivalent area underneath the curve and therefore essentially the same significant wave height. The sharp peak in the Ochi spectrum occurs at a radian frequency of 0.4 radians per second which is equivalent to a long swell with approximately a 16 second period. The broader peak of the Bretschneider spectrum occurs at a radian frequency of 1.25 radians per second which would be the equivalent of a shorter wave with a 5 second period. Such drastic differences in wave periods will result in noticeably different motion characteristics of the CPF.

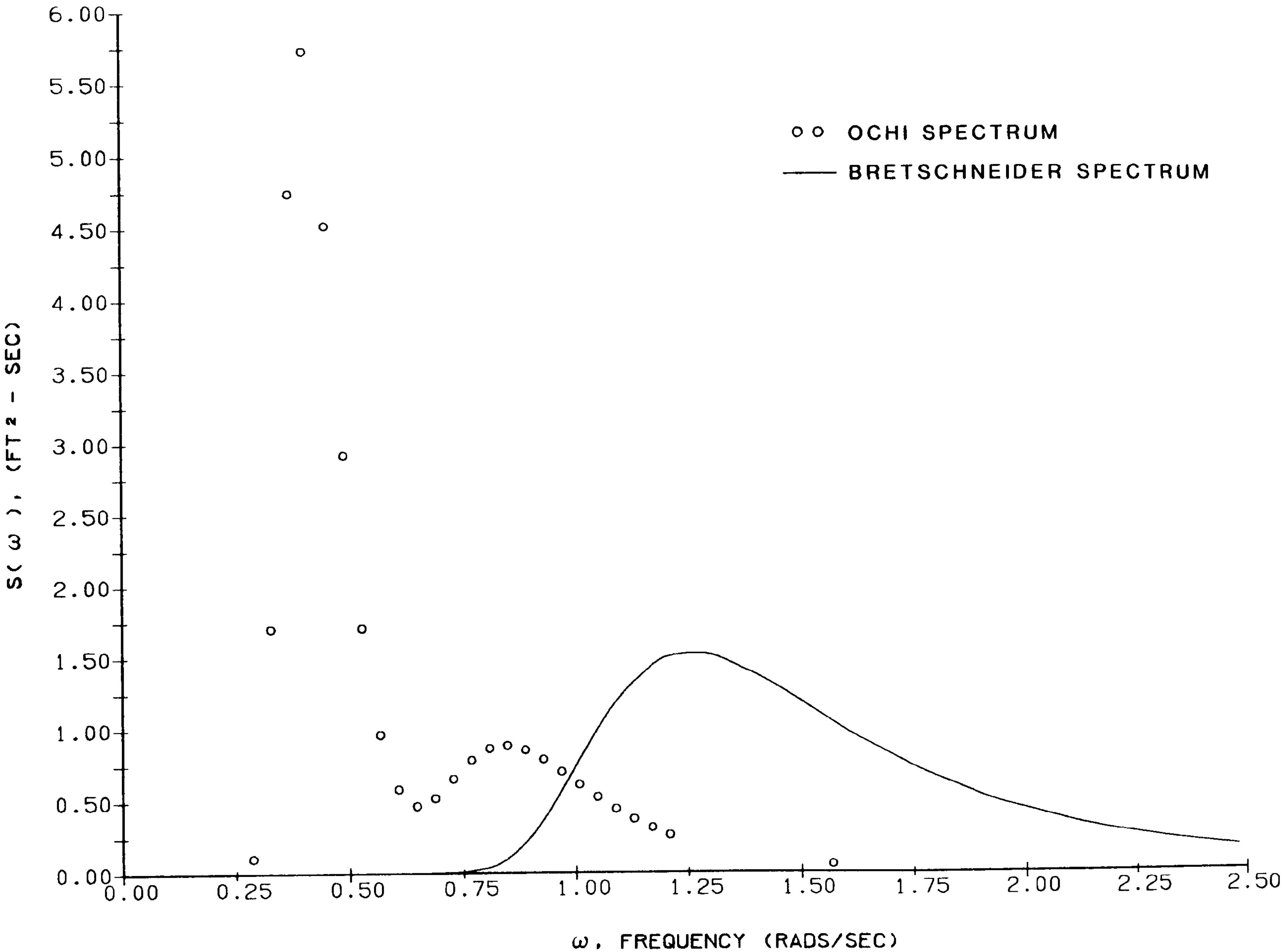


Figure 8 Comparison of Sea Spectra Used in Analysis

3.4 Modelling Configurations

The configurations of the CPF that are considered in the motion analysis are shown in Figures 9 through 13. Figure 9 is a plan view of the baseline CPF and illustrates the sign convention and some of the nomenclature used in this analysis. The longitudinal axis (x) of the CPF is aligned with the length of each causeway section and also defines the head seas direction. Because of platform symmetry this can also be considered as following seas. Roll motion is defined as rotation about this axis. The y-axis is aligned with the breadth of each causeway section and also defines the beam sea direction. Pitch motion is defined as rotation about this axis. The quartering seas direction is 45 degrees between head and beam seas and is indicated also. In reference to the terminology used with AQWA and indicated on all output plots contained in this report and appendices, the structure number of each section is indicated in the center of each section. Nodal points along the edge of the CPF are indicated also and are useful in calculating relative motion between the deck edge and the water surface for quantifying deck wetness.

The three dimensional panel models of the sealift barge, the partially articulated CPF, and the 4 x 1 NA Pontoon CPF used in the motion predictions are illustrated in Figures 10, 11, and 12, respectively. Figure 11 also is the model for the baseline CPF, the only difference being in the modelling of the connections between the sections. The 10 section CPF is modelled in a similar fashion as the baseline CPF and the plan view shown in Figure 5 is not repeated. Figure 13 (a and b) illustrates the locations of the roll damping devices on the CPF which are modelled in this analysis. The rationale for sizing the dampers is based on references 9 and 10. The locations are based on establishing the upper limit of roll damping capability. This rationale is explained in further detail in Section 4.2.

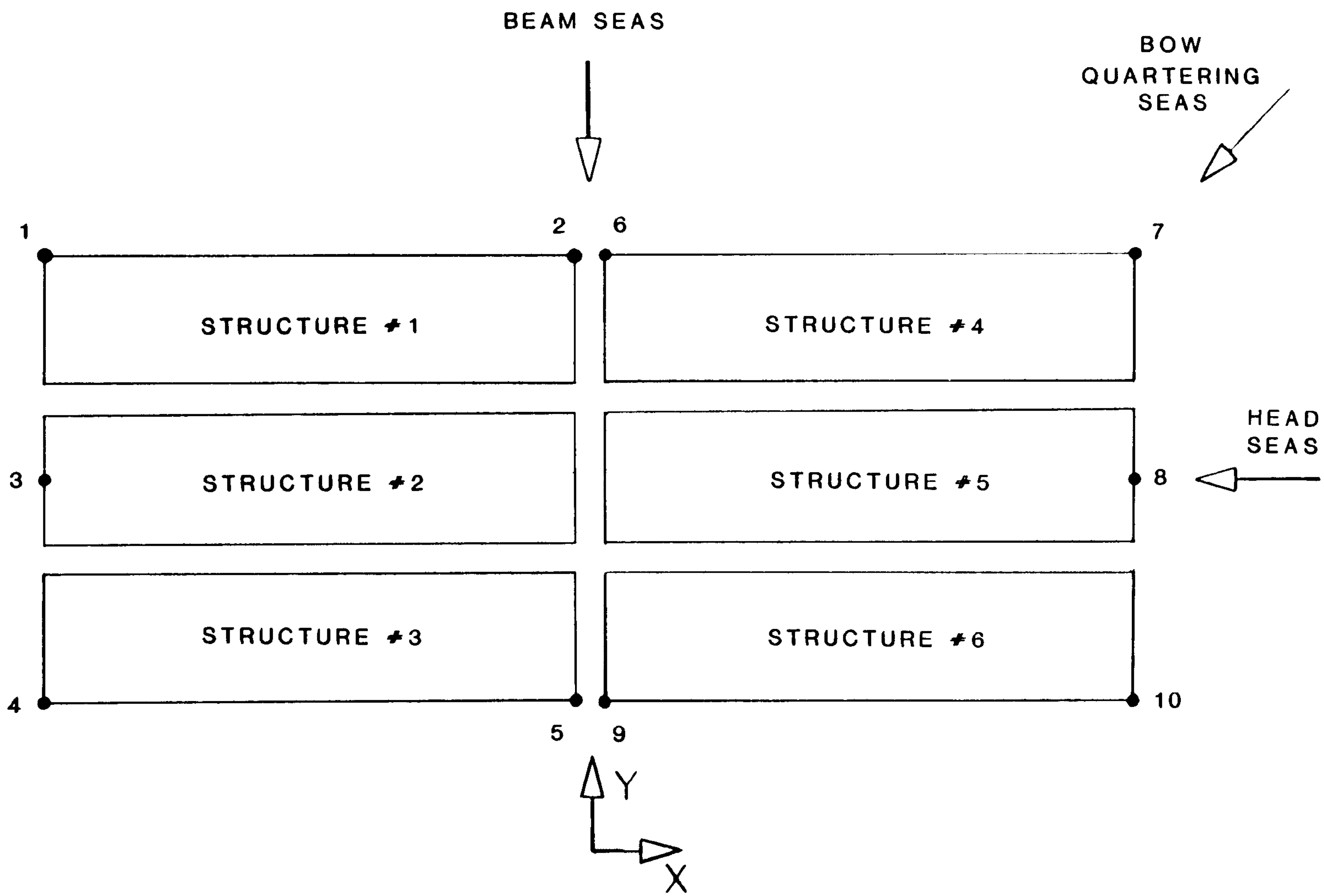


Figure 9 Baseline CPF and Sea Direction Definition

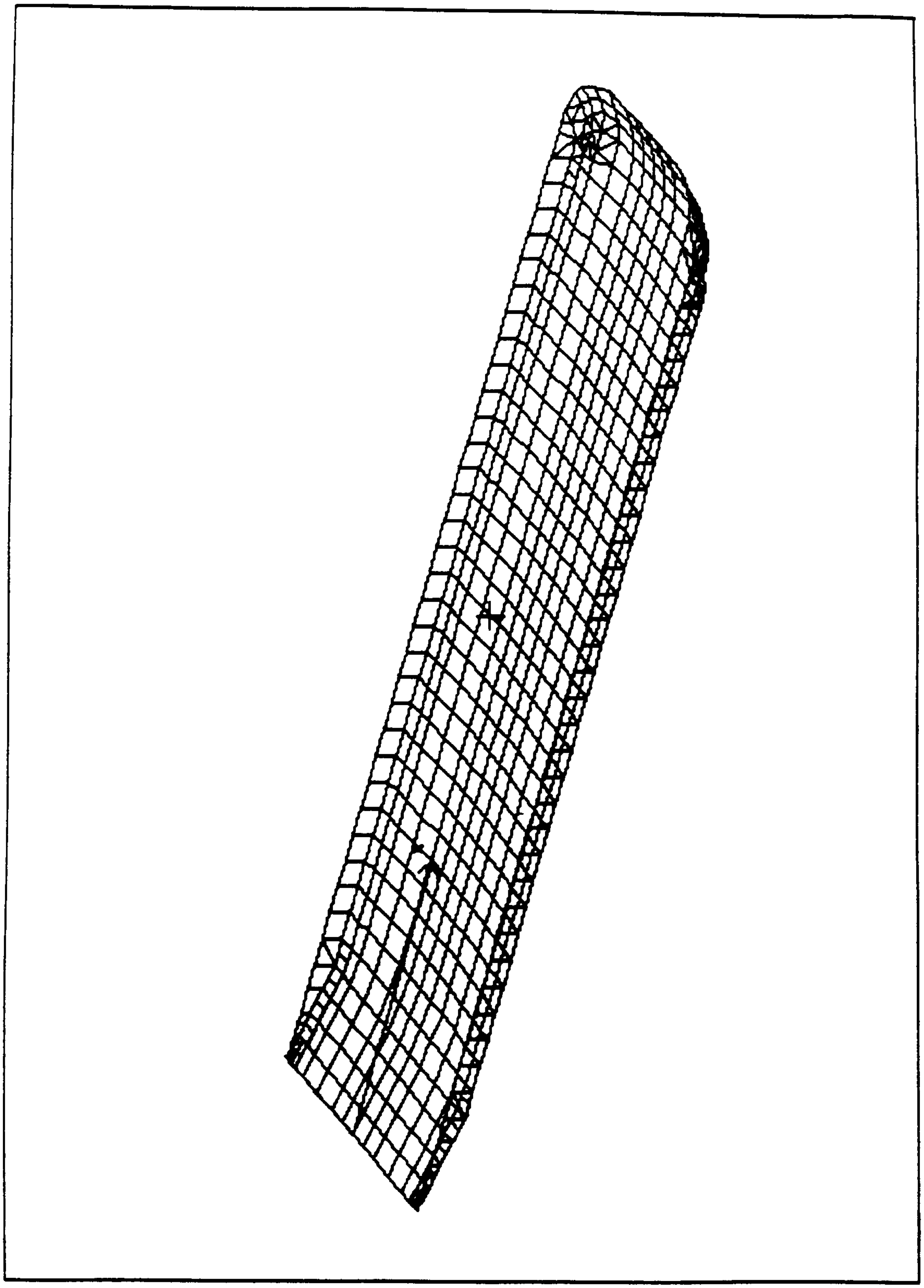


Figure 10 Sealift Barge Panel Model

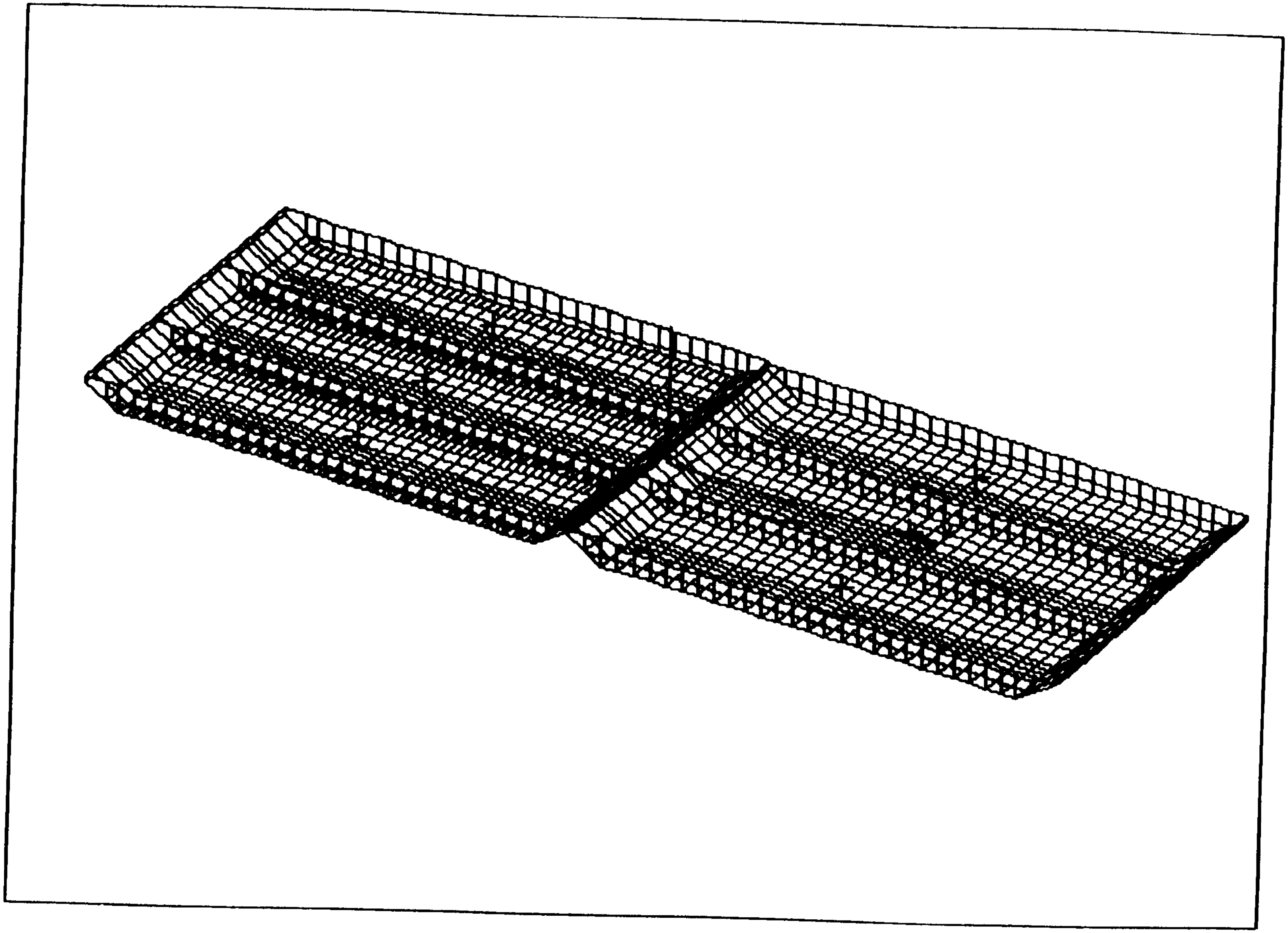


Figure 11 Partially Articulated CPF Panel Model

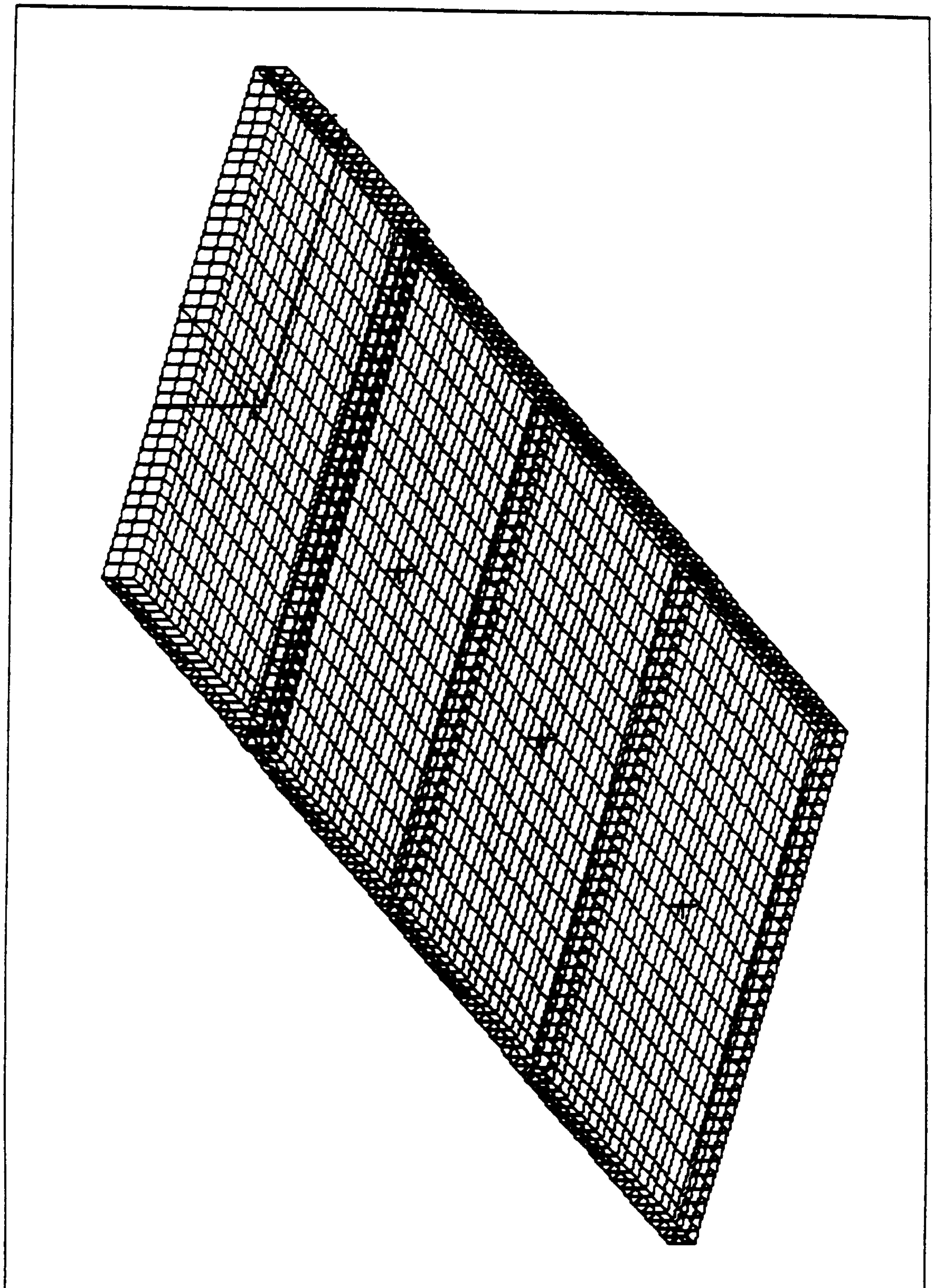


Figure 12 NA Pontoon CPF Panel Model

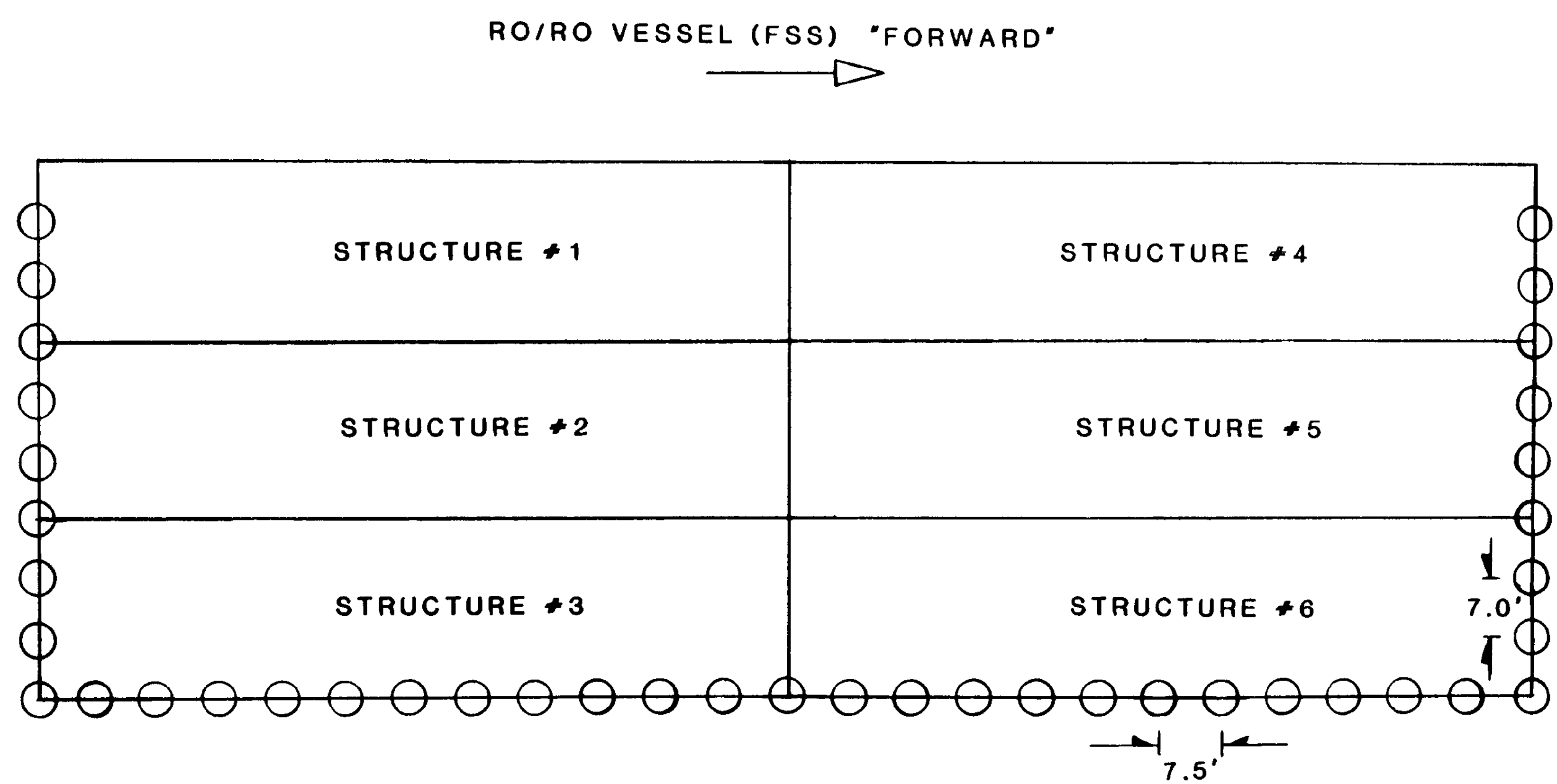


Figure 13a Baseline CPF with Roll Dampers (Initial Configuration)

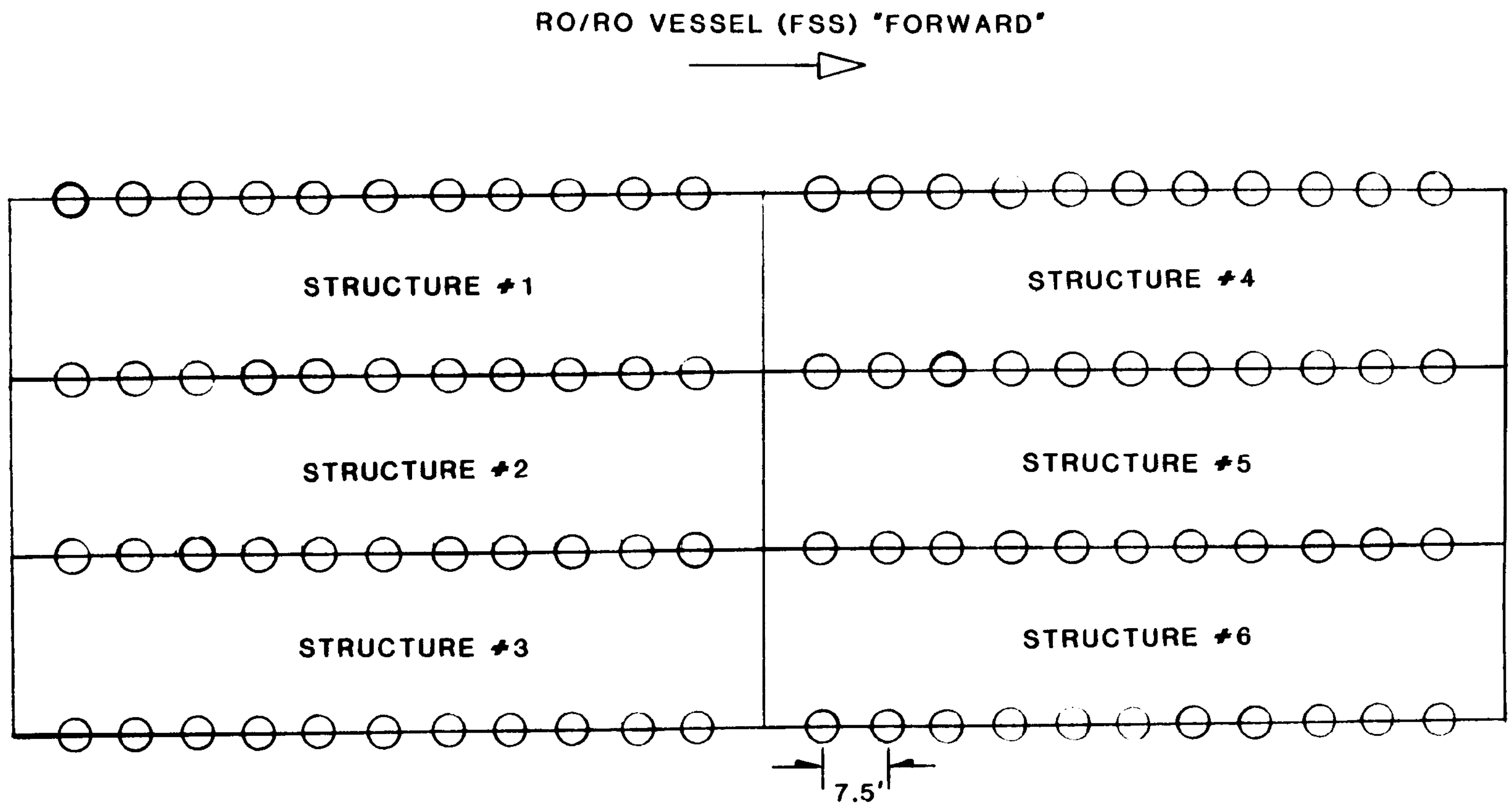


Figure 13b Increased Damping Configuration of CPF

4.0 RESULTS OF PREDICTED MOTIONS ANALYSIS

The matrix of all the AQWA calculations contained within this analysis is listed in Table 4-1. As a starting point, the motions of the baseline CPF are calculated in a seaway approximately equivalent to the conditions that the RRDF has previously experienced. The significant motions are established as a target for acceptable limits in examining the other concepts. The effect of directionality of the seaway is also considered by analyzing the motions in head, quartering, and beam seas.

The analysis of the various proposed RRDF configurations in Sea State 3 is further subdivided into three series of calculations. The first analysis compares the baseline CPF with two configurations of the roll-damped concept in a Sea State 3 Bretschneider spectrum. Since there are some very distinct near term possibilities of installing dampers in a non-disruptive fashion during an exercise, it is worthwhile devoting a significant effort to analytically modelling this configuration. This analysis is also the most complex and deserves additional attention and consideration.

The next series of calculations examines the other four concepts in a Sea State 3 description that is more heavily dominated by long swells. Operational problems have been experienced in this type of environment due to the large relative motions between each section since the articulated platforms tend to contour the wave profiles. The effect of directionality is considered and the likelihood of deck wetness being a problem is addressed.

The final series of calculations compares the deck wetness and motions of the baseline CPF and the concepts in a fresh Sea State 3. The previous analyses indicate that the likelihood of deck wetness is greater in head seas due to the pitching responses of the sections. Without a multi-point mooring configuration, it is more likely that the mooring of the RO/RO ship will result in a head seas condition for the CPF. For these reasons and due to an interest in limiting the computational effort, the analysis in this series is limited to the head seas condition.

Table 4-1

Matrix of AQWA Calculations

SEA DESCRIPTION	HEADINGS	CONCEPTS	PURPOSE
Bretschneider Sea State 2	Head Quarter Beam	Baseline CPF	Motion Limits Established
Bretschneider Sea State 3	Head Quarter Beam	Baseline CPF Damped CPF	Compare Roll Damping Concept with Baseline
Ochi Sea State 3	Head Quarter Beam	Baseline CPF Damped CPF Sealift Barge Partially Art. CPF 10 Section CPF NA Pontoon CPF	Compare Concepts in Swells Examine relative motion between sections Establish likelihood of deck wetness
Bretschneider Sea State 3	Head	Baseline CPF Damped CPF Sealift Barge Partially Art. CPF 10 Section CPF NA Pontoon CPF	Compare deck wetness and motions of each concept in Sea State 3.

4.1 Baseline Condition Analysis

To begin the motions analysis, the baseline CPF seakeeping characteristics are compared in Sea States 2 and 3 as described by a Bretschneider spectrum. This Sea State 2 spectrum is very close to that measured during previous exercises and reported in References 4 and 6. The motions of the baseline CPF are calculated in head, quartering, and beam seas to gain some insight into the effect of directionality. Table 4-2 is a summary of the significant single amplitude of motions calculated over a 200 second record length. The results are tabulated for structure number 5, which is at the foot of the discharge ramp, and for structure number 3, which is at the outboard edge of the RRDF. As a measure of merit, throughout this report the value of the significant motions of these two locations will be compared.

TABLE 4-2
BASELINE CPF COMPARISON
SEA STATES 2 & 3

Structure 5 - Foot of Ramp

Significant Motion	HEAD SEAS Sea State 2	HEAD SEAS Sea State 3	QUARTERING SEAS Sea State 2	QUARTERING SEAS Sea State 3	BEAM SEAS Sea State 2	BEAM SEAS Sea State 3
Heave (Ft)	0.11	0.6	0.11	1.0	0.50	1.9
Pitch (Deg)	0.3	2.0	0.23	1.8	0.23	1.1
Roll (Deg)	0.0	0.0	0.33	1.8	3.42	7.8

Structure 3 - Outboard Edge of RRDF

Significant Motion	HEAD SEAS Sea State 2	HEAD SEAS Sea State 3	QUARTERING SEAS Sea State 2	QUARTERING SEAS Sea State 3	BEAM SEAS Sea State 2	BEAM SEAS Sea State 3
Heave (Ft)	0.09	0.8	0.11	1.3	0.53	1.9
Pitch (Deg)	0.28	2.0	0.18	1.7	0.23	1.0
Roll (Deg)	0.49	2.8	0.64	4.8	2.50	5.9

Inspection of Table 4-2 leads to a number of conclusions. The baseline CPF does not appear to behave in a purely linear fashion, as indicated by the relatively greater increase in motions with the increase in significant wave height. As a result of this, it is clear that the effectiveness of any proposed concept would need to be considerable in order to meet the target motion limits as predicted for Sea State 2. The calculated motions in Sea State 2 are also in reasonably good agreement with those reported during the JLOTS exercises. An exact comparison is not really very meaningful due to the fact that these calculations are made in an idealized seaway that is unidirectional and the exercises were conducted in a non-uniform seaway with obvious directionality effects included.

At the foot of the discharge ramp, the highest motions in either sea state tend to occur in the beam sea case. This is due largely to the roll response of the section on which the ramp sets. The roll amplitude in Sea State 3 is large enough to be of concern for operational reasons. This is consistent with observations during previous exercises. It is also very significant in that large torsional structural loads could be imparted to the ramp if a vehicle were to be offloaded while the causeway section was rolling this much. In the head seas case, the pitch motion is dominant and within a generally acceptable limit.

At the outboard edge of the RRDF there are some interesting motions indicated by these calculations. In the head seas case, the heave and pitch motions are about the same as those calculated at the center of the RRDF near the ramp. The exception is that this section tends to roll in head seas. This is not a normal response for a single floating body and is probably the result of the articulated nature of the platform. One edge of this section is constrained to move with its adjacent section while the outboard edge is free to respond. This leads to a tendency for a "flapping" type of motion. This phenomena is also evident in the beam seas case where the section tends to pitch. Also in the beam seas case, this section tends to roll a little less which is probably due to the constraints of the inboard sections.

The head seas case tends to result in the highest pitch motions and also exhibits some non-trivial roll motion at the outboard edge of the CPF. Single point mooring configurations which are currently in practice are most likely to result in the RRDF oriented in a head seas configuration. For these reasons, head seas will be considered for each concept in the evaluation of the likelihood of deck wetness effects.

4.2 Analysis of Roll-Damped Configuration

Since there is some near-term possibility of developing prototype roll dampers for deployment during a future exercise, the next phase of the motions analysis compares the motion of the baseline CPF with that of the roll-damped CPF. In order to simulate the effect of placing roll dampers on the CPF sections, the damping coefficient matrix in the mathematical model of the CPF must be modified. The calculation of the additional damping contribution of the "flopper-stoppers" is based upon the methodologies described in References 9 and 10. The effect of the individual dampers on the heave, pitch, and roll damping due to their locations around the CPF is considered in the calculation. The initial attempt at modelling this concept corresponds to the configuration illustrated in Figure 13(a) and will be referred to as the lightly damped concept. Table 4-3 is a summary of the significant motions of this damped configuration calculated over a 200 second record length in a Sea State 3 Bretschneider spectrum.

TABLE 4-3
SEA STATE 3 COMPARISON - BRETSCHNEIDER SPECTRUM
BASELINE CPF AND LIGHTLY ROLL DAMPED CONCEPT

Structure 5 - Foot of Ramp

Significant Motion	HEAD SEAS Baseline CPF	HEAD SEAS Damped CPF	QUARTERING SEAS Baseline CPF	QUARTERING SEAS Damped CPF	BEAM SEAS Baseline CPF	BEAM SEAS Damped CPF
Heave (Ft)	0.6	0.6	1.0	0.9	1.9	2.0
Pitch (Deg)	2.0	2.0	1.8	1.5	1.1	0.7
Roll (Deg)	0.0	0.0	1.8	1.7	7.8	9.0

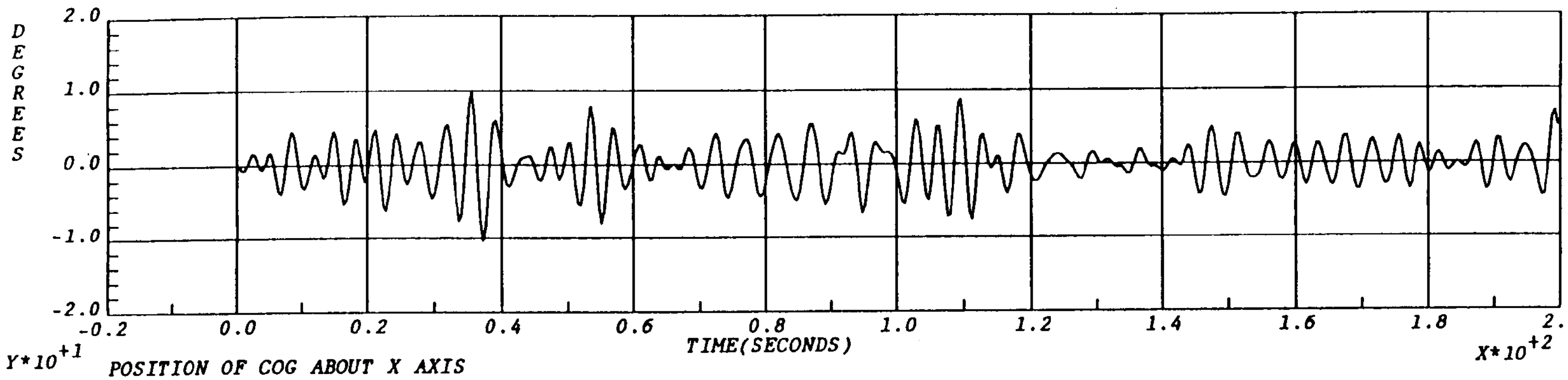
Structure 3 - Outboard Edge of RRDF

Significant Motion	HEAD SEAS Baseline CPF	HEAD SEAS Damped CPF	QUARTERING SEAS Baseline CPF	QUARTERING SEAS Damped CPF	BEAM SEAS Baseline CPF	BEAM SEAS Damped CPF
Heave (Ft)	0.8	0.7	1.3	1.2	1.9	2.0
Pitch (Deg)	2.0	1.8	1.7	1.3	1.0	0.8
Roll (Deg)	2.8	2.8	4.8	4.1	5.9	7.8

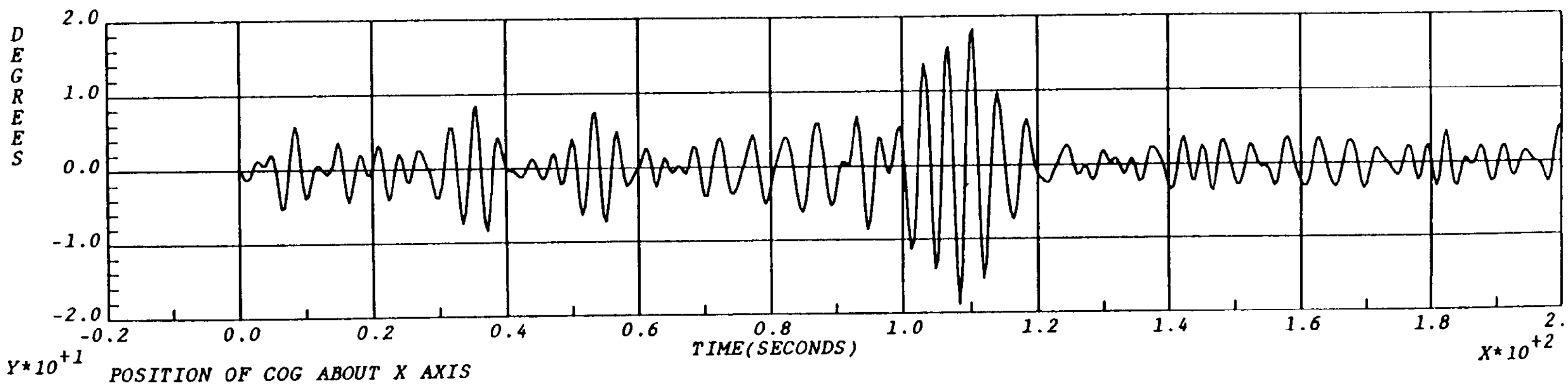
At the foot of the ramp in head seas there are no discernible differences in the significant motions of the section. This is not particularly surprising due to the few dampers that are located on this section in this model. Although there are many more dampers located on the outboard edge of the CPF, the effect of these on the significant motions of the center section appears to be negligible. In quartering seas the damped CPF appears to have very slightly reduced significant motions as compared with the baseline. In the beam sea case there appears to be a rather strange anomaly in that the damped CPF's significant roll motions are actually greater than those of the baseline.

At the outboard sections of the CPF the significant motion characteristics of the damped concept follow the same trends as the baseline with the exception of the roll motion in beam seas. In this case the damped CPF is calculated to have a higher significant roll motion than the baseline. Since the calculation of significant values of motion is based on the entire record length, it is necessary to examine the calculated time history of motion in order to more fully address this anomaly. Figure 14 illustrates the roll motion time histories for the baseline and the lightly damped CPF in a Sea State 3 Bretschneider spectrum. On inspection, it is clear that the calculated significant roll motion of the damped CPF is dominated by a transient response which begins at approximately the 100 second mark. There is a similar, although not as pronounced, peak of responses in the baseline CPF motion during the same time period. The record length of this calculation was chosen to minimize computing costs and yet still produce a statistically reliable sample. Truncating the data around the transient responses would probably yield a record length that was too short for meaningful numerical analysis. From a qualitative viewpoint, however, the roll motions of the damped sections do appear to be slightly smaller than those of the baseline outside of the areas of the large transient in the record length.

In order to adequately resolve this anomaly, it is necessary to consider the input side of this analysis. Examining the time history of the incident wave field which was generated for the motion response calculations helps to determine the relationship of the wave field to the larger motions of the damped CPF. Figure 15 illustrates the time history of the incident wave height. Two separate locations (labelled points A and B) are shown to verify the longcrested nature of the waves. These two points are on the outboard edge of the CPF and thus, a line connecting the two points would be parallel to the incident wave crest. It is interesting to note the large wave just prior to the 100 second mark. This wave is significantly larger than most of the others and the resulting motion of the CPF sections appears to be some sort of resonance.

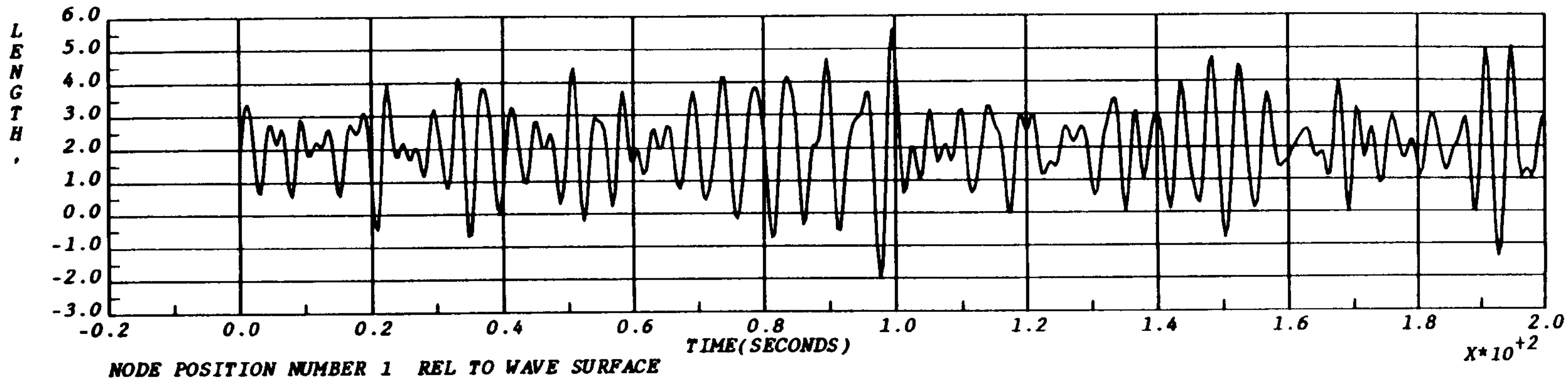


a) Baseline CPF without Roll Dampers

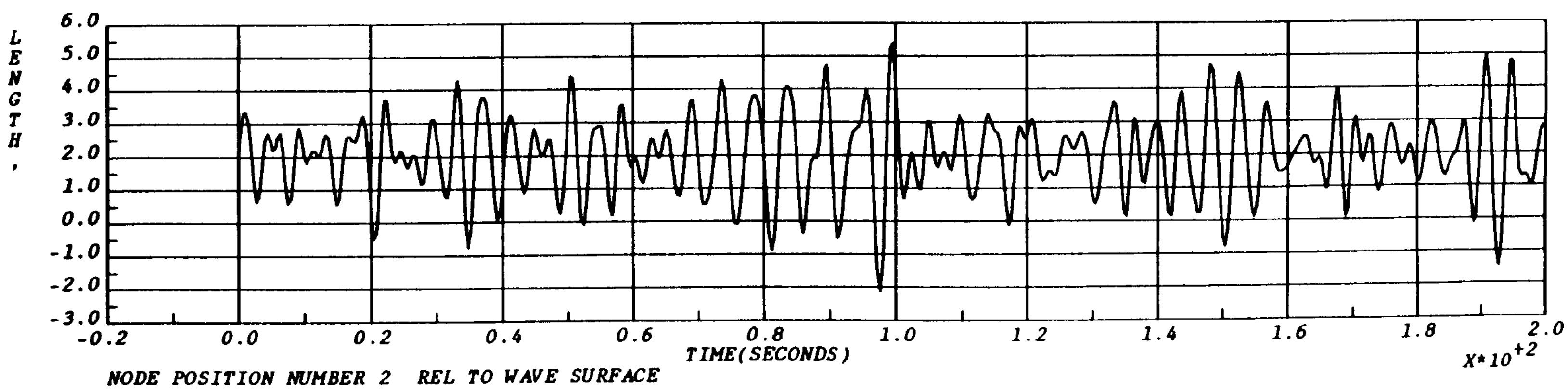


b) Baseline CPF with Roll Dampers (Initial Configuration)

Figure 14 Comparison of Roll Motion Time Histories on Structure #3 in Beam Seas, Sea State 3, Bretschneider Spectrum for Baseline CPF without Roll Dampers and Baseline CPF with Roll Dampers (Initial Configuration)



a Wave Elevation at Point A



b Wave Elevation at Point B

Figure 15 Wave Elevation at Points A and B

A more heavily damped configuration of the CPF was modelled to establish the absolute maximum limit of damping that could be feasibly installed. The damping coefficient matrix was modified further to reflect the contributions of the dampers illustrated in the configuration shown in Figure 13(b). Calculations of the significant motions in beam seas only were made. This limitation on headings was chosen because the beam seas case had previously illustrated the anomaly and that there was a desire to minimize computational costs. Table 4-4 lists the resulting significant motions at the foot of the ramp on structure number 5. The same unusual trend that was previously evident is shown in the results of these calculations. The heave motion of the damped CPF is slightly greater than that of the baseline. The pitch motion of the damped CPF shows a reasonable reduction as compared to the baseline, however, the roll motion of the damped CPF seems to have a substantial increase as compared to the baseline.

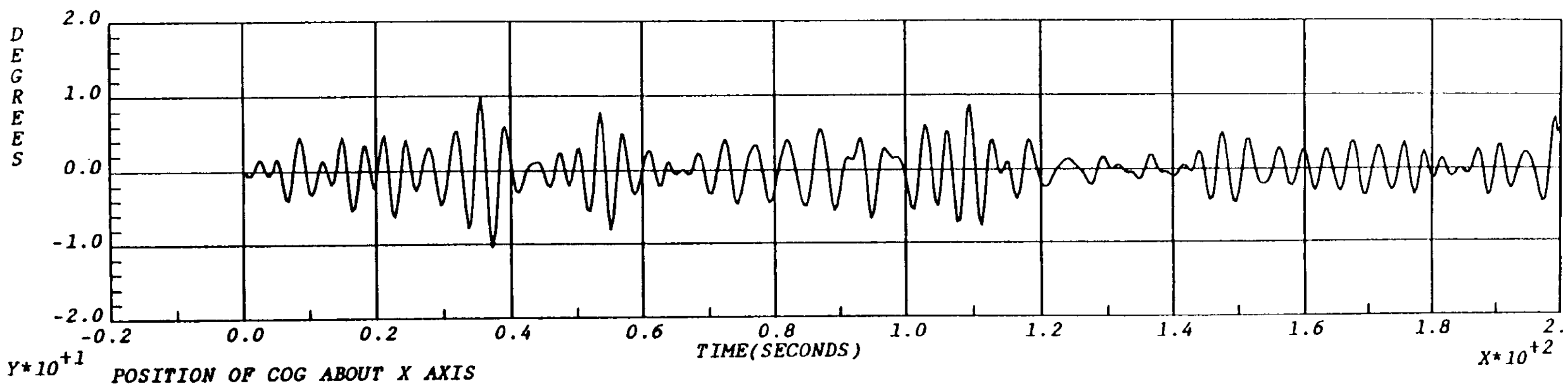
TABLE 4-4

SEA STATE 3 COMPARISON - BRETSCHNEIDER SPECTRUM

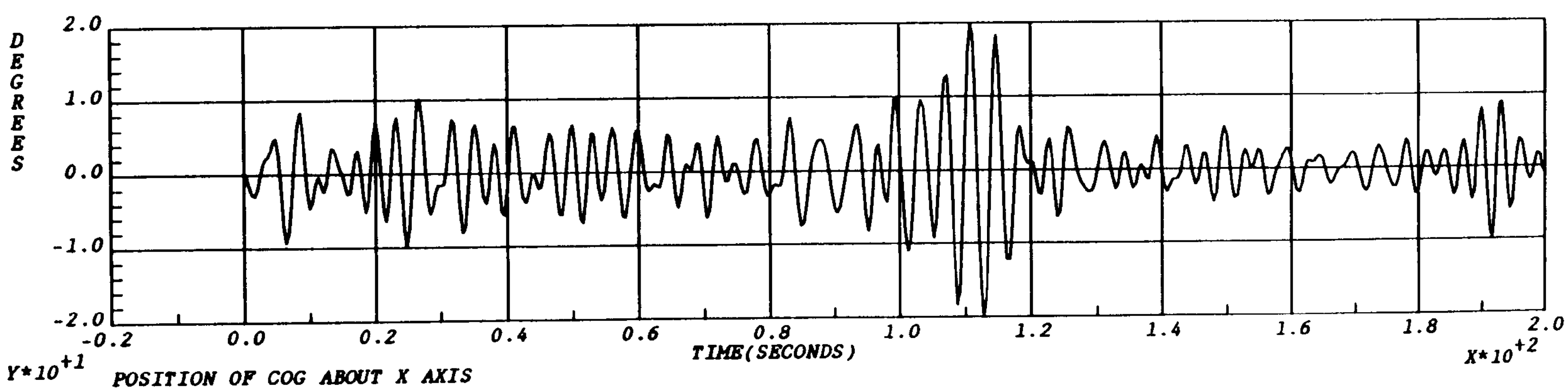
BEAM SEAS

Significant Motion	Baseline CPF	Heavily Damped CPF
Heave (FT)	1.9	2.0
Pitch (DEG)	1.1	0.7
Roll (DEG)	7.8	11.8

Figure 16 illustrates a comparison of the roll motion time histories of the baseline CPF and the more heavily damped CPF in beam seas. It is clear from this figure that the same inexplicable response of the damped CPF is present at the 100 second point.



a) Baseline CPF without Roll Dampers



b) Increased Damping Configuration of CPF

Figure 16 Comparison of Roll Motion Time Histories on Structure #3 in Beam Seas, Sea State 3, Bretschneider Spectrum for Baseline CPF without Roll Dampers and Baseline CPF with Increased Roll Damping

The numerical models of the roll-damped CPF have not yielded any conclusive results. This effort represents an attempt to analytically model a hydrodynamically complex phenomena and it is very doubtful that increasing the damping in an articulated system such as the CPF will result in an increase in the wave-induced motions of the platform sections. The modelling technique was pushed to its limits and it is clear that some further empirical data is required. Quantifying the effect of roll damping on ship motions is typically accomplished by the inclusion of some experimental data base in the calculation routine. It is highly recommended that in order to quantify the effects of roll dampers on the motions of the CPF, an experimental program be initiated both in model scale and by using prototypes in the field. Due to the inconclusive nature of the motion predictions of the damped CPF, this concept will not be included in the parametric analysis in Section 5 of this report.

4.3 Comparison of Concepts in Swells

A comparison of the relative motions between sections of the CPF is best made by examining the motion in an Ochi spectrum. Since this wave field is heavily dominated by the swell component, the individual sections will tend to conform to the wave profile and the relative motion between sections will be greatest. Table 4-5 summarizes the significant motions at various headings at the foot of the ramp of the baseline and the four additional concepts in the Ochi spectrum Sea State 3 described in Figure 8. In head seas, only heave and pitch are tabulated since the roll motion was essentially zero. This is somewhat different from the calculations using the Bretschneider spectrum and is probably due to the large differences in the dominant wavelengths in the two spectra. In quartering seas, all motions are tabulated. In beam seas, only heave and roll are tabulated for the same reasons as indicated in the head seas case.

TABLE 4-5
COMPARISON OF DIRECTIONALITY EFFECTS

Sea State 3 - Ochi Spectrum

CPF Concept	HEAD SEAS Heave/Pitch	QUARTERING SEAS Heave/Pitch/Roll	BEAM SEAS Heave/Roll
Baseline CPF	1.8/1.6	1.8/1.4/1.0	2.0/2.7
Sealift Barge	1.1/0.7	1.5/0.7/0.6	2.1/2.6
Partially Articulated CPF	1.7/2.1	1.8/1.6/1.1	2.1/2.7
10 Section CPF	1.7/1.9	1.8/1.2/1.0	2.0/2.8
NA Pontoon CPF	1.9/2.2	1.8/1.6/0.9	1.8/2.0

On inspection of the significant motions in the beam seas case, these concepts all appear to be fairly similar to each other with the NA Pontoon CPF having slightly lower significant motions. This result is not surprising since each concept has similar natural roll characteristics and is in the presence of very long waves. In the quartering seas case, the sealift barge generally has the best performance while the other concepts are fairly similar to each other. In the head seas case, the sealift barge clearly exhibits the best motion characteristics. The partially articulated CPF has larger significant pitch motions which is probably a result of the orientation of the articulation with respect to the swell direction. The 10 section CPF and the NA Pontoon CPF appear to have motion characteristics which are very similar to each other.

In an overall sense, the sealift barge appears to have the lowest significant motions in a swell dominated seaway. The magnitudes of the various motions of this concept are all within acceptable limits. However, all the calculated motions of this concept are slightly higher than those of the baseline CPF in Sea State 2 with the exception of roll in beam seas. In this instance the sealift barge shows a slight reduction in significant roll amplitude. Certainly the benefits gained in the motion characteristics of this concept must be balanced against expected costs and transportability. This will be addressed in greater detail in Section 5 of this report.

In an attempt to quantify the likelihood of deck wetness being a problem in this sea state, the height of the water surface relative to the deck edge of the CPF can be examined. Deck wetness will be manifested either in the form of green water on deck or wind-blown spray. In this analysis, if the height of the water surface reaches the deck edge, then green water on deck is imminent. Spray is not possible to calculate using this technique since the analysis breaks down in this region and wind effects are not considered. It is possible, however, to at least consider a qualitative assessment of the likelihood of spray based on the height of the water surface relative to the deck edge.

In this swell-driven seaway with a modal period of approximately 16 seconds, the CPF sections essentially follow the wave profile and therefore the relative height of the water surface hardly changes. It is clear that green water on deck is highly unlikely. For the sake of qualitative analysis of spray likelihood, the probability that the distance from the deck edge to the instantaneous water surface is less than 75% of the still water freeboard is a reasonable measure of merit. Of all the cases listed in Table 4-5, this calculated probability is negligible and the differences between each concept are hardly distinguishable.

To carry the analysis a step further, the Baseline CPF was examined in an Ochi spectrum with the same significant wave height (therefore having the same energy and also being a Sea State 3) but with the modal period adjusted to be closer to the natural periods of the causeway sections. For this spectral description the modal periods were 8.4 and 4.1 seconds. There is still no evidence of green water on deck being a problem but the measure of likelihood of spray is on the order of 10% for the worst case, which is the head seas orientation.

4.4 Comparison of Concepts in a Fresh Seaway

As a final comparison, the motions and deck wetness implications for the baseline and the four concepts are examined in a Sea State 3 Bretschneider spectrum. As previously shown in the Ochi spectrum analysis, the likelihood of deck wetness being evident is greater in the head seas orientation. For this reason, and because of the need to minimize computational costs, this analysis in the Bretschneider spectrum is limited to the head seas case. Table 4-6 summarizes the significant heave and pitch motions at the foot of the ramp for each configuration. There also is an indirect measurement of the likelihood of deck wetness in the form of spray being experienced in this seaway. The measure expressed is a ranking factor (1 is best) based on the percent probability of occurrence that the local freeboard at a point on the centerline of the leading edge of the platform will be less than 75% of the still-water freeboard. This is not meant to be an absolute expression of deck wetness probability but will give reasonable insight into relative trends.

TABLE 4-6
SEA STATE 3 HEAD SEAS COMPARISON
BRETSCHNEIDER SPECTRUM

CPF CONCEPT	HEAVE (FT)	PITCH (DEG)	DECK WETNESS RANKING
BASELINE CPF	0.6	2.0	2
SEALIFT BARGE	0.3	0.2	1
PARTIALLY ARTICULATED CPF	0.7	2.6	5
10 SECTION CPF	0.6	2.0	3
NA PONTOON CPF	1.1	4.4	4

It is clear from this table that the sealift barge exhibits the best motion characteristics. In fact, the motions of this CPF concept are substantially lower than any other concept in Sea State 3 and are essentially equal to the baseline CPF in Sea State 2. The significant heave of the sealift barge in Sea State 3 is actually slightly greater than that of the baseline CPF in Sea State 2 while the significant pitch of the barge is slightly lower than that of the baseline. The baseline CPF and the 10 section CPF, have the same significant motions over the entire record length. The partially articulated CPF and the NA

Pontoon are the poorer performers of the group. This would appear to be due to the orientations of their articulations with respect to the wave directions.

4.5 Motion Performance Ranking

A summary table of an overall ranking of each concept based on motion characteristics is given in Table 4-7. There is some subjectivity in this table since a qualitative interpretation of the motion data is required in some cases.

TABLE 4-7
RANKING OF CPF CONCEPTS
SEA STATE 3 MOTION CHARACTERISTICS

1. SEALIFT BARGE
2. BASELINE CPF
3. 10 SECTION CPF
4. PARTIALLY ARTICULATED CPF
5. NA PONTOON CPF

The sealift barge is the clear winner and is probably in a class by itself when considering the motions analysis. The motions characteristics of this concept in a Sea State 3 are essentially equal to, and in the case of pitch might be slightly better than, the baseline CPF in a Sea State 2. The motions of the other 4 CPF configurations in a Sea State 3 are much more substantial than the baseline CPF in a Sea State 2 and in some instances may prove to be hazardous to personnel and equipment. From the standpoint of motion characteristics alone, the sealift barge is the only one of these concepts that shows any promise of operation in a Sea State 3. Due to the inconclusive nature of the analytical assessment of the roll-damped configuration, this concept should not be eliminated from consideration without further experimental investigation.

5.0 PARAMETRIC ANALYSIS OF CONCEPTS

A parametric analysis allows for a consistent, systematic approach for a quantitative comparison of options or concepts consisting of many different parameters. Defining the parameters, relative weights, and utilities can be accomplished by knowledgeable engineers familiar with the specific project and a variety of engineering judgments can be combined into a final ranking of each concept.

A systems engineering approach following four basic steps is used to perform the parametric analysis. A hierarchy of the parameters important for the concepts is established first. Relative weights describing the importance of each parameter then are defined. Dimensionless utilities or values of each parameter are identified which when combined with the relative weights following the path established in the hierarchy will ultimately lead to a score for each option. Finally, a generic cost consideration is given to interpret the results.

5.1 Parametric Hierarchy

In order to systematically establish the parametric hierarchy for this analysis, a survey was conducted. Engineers and operators familiar with the RRDF and similar operations were queried and the results compiled. Final analysis and distillation of the surveys was accomplished and the hierarchy shown in Figure 17 was developed.

In this figure, the parameters and their relative weights are indicated. Across any horizontal line, the sum of the relative weights is equal to 1. The value of the individual parameter is multiplied by its weighting factor and then this product is added to the others on the same horizontal line. The resulting sum is then added to the one above, and the process through the hierarchy continues until a final number results at the top of the hierarchy.

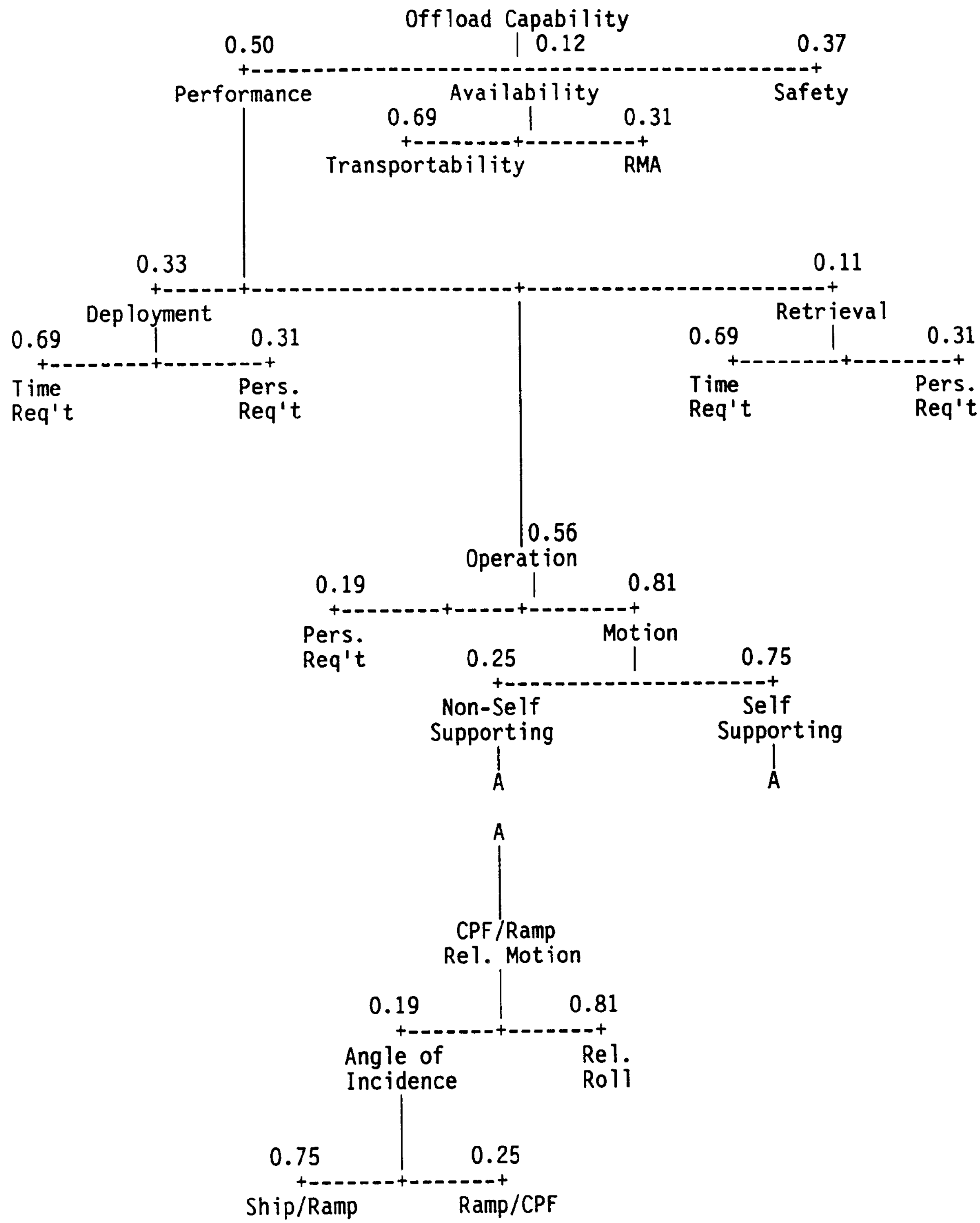


Figure 17 Parametric Hierarchy

5.2 Calculated Values for Parameters

Following definition of the hierarchy of parameters and the relative weights of each, the next critical steps involve quantifying the parameters for each option and reducing the values of the parameters to a dimensionless value between 0 and 1. Quantifying the parameters is accomplished through the motions analysis and by applying sound engineering judgement to the other related parameters. Reducing the motion related values of parameters to non-dimensional quantities is accomplished by creating and using utility curves.

Table 5-1 lists the calculated values of the motion related parameters for the baseline CPF and four of the proposed concepts. Due to the inconclusive nature of the analysis of the roll damped CPF, this concept is not included in this analysis.

TABLE 5-1
MOTION PARAMETER VALUES
IN BRETSCHNEIDER SPECTRUM

Parameter	Baseline CPF	Sealift Barge	Part. Art. CPF	10 Section CPF	NA Pontoon CPF
Angle of Incidence Ship/Ramp (DEG)	10.3	10.1	10.3	10.3	10.5
Angle of Incidence Ramp/CPF (DEG)	7.7	9.7	7.1	7.7	5.1
CPF/Ramp Relative Roll (DEG)	0.0	0.0	0.0	0.0	0.0

MOTION PARAMETER VALUES
IN OCHI SPECTRUM

Parameter	Baseline CPF	Sealift Barge	Part. Art. CPF	10 Section CPF	NA Pontoon CPF
Angle of Incidence Ship/Ramp (DEG)	5.6	5.4	5.6	5.6	5.6
Angle of Incidence Ramp/CPF (DEG)	2.5	3.3	2.2	2.5	2.2
CPF/Ramp Relative Roll (DEG)	1.0	0.6	1.1	1.0	0.9

Table 5-1 is divided into 2 sections. The Bretschneider spectrum data is most applicable to NSS RO/RO vessels since these cases were only considered in a head seas orientation. The Ochi spectrum data is a summary of the quartering seas orientation and is therefore most applicable to SS RO/RO vessels. The ship/ramp angle of incidence is defined as the angle in the vertical plane between the centerline of the ramp and the horizontal line through the top end support of the ramp. The change in this angle is due to heaving at the foot of the ramp. The angle of incidence of the ramp/CPF is defined as the angle in the vertical plane between the ramp and the deck of the CPF. The change in this angle is due to the heaving and pitching motion of the CPF. The CPF/Ramp relative roll angle is due to the roll motion of the CPF since the ship motions are considered to be negligible. Figure 18 illustrates these angles.

The assumed geometry in still water is that for a generic ramp length of 120 feet with a 4.7 degree slope for SS RO/RO vessels and a 10 degree slope for NSS RO/RO vessels. The ramp is assumed to be rigid and the 120 foot length is considered as a nominal length. This geometry does not necessarily represent any particular ramp. The slopes chosen for the NSS and SS RO/RO vessel/ramp combinations are considered to be typical as there are many combinations of ship geometries and loading conditions that will result in various still water ramp slopes.

The motion related values listed in Table 5-1 are reduced to non-dimensional quantities for this analysis by using the utility curves shown in Figure 19. These curves were developed for this analysis and are somewhat arbitrary although there is a specific logic behind their development. The significant roll angle utility curve illustrated in Figure 19 (a) starts at a value of 1.0 for zero roll. Small roll angles have little effect and therefore the curve is fairly "flat" on top and drops off much more rapidly as the roll angle increase. A seven degree relative roll angle is considered the upper

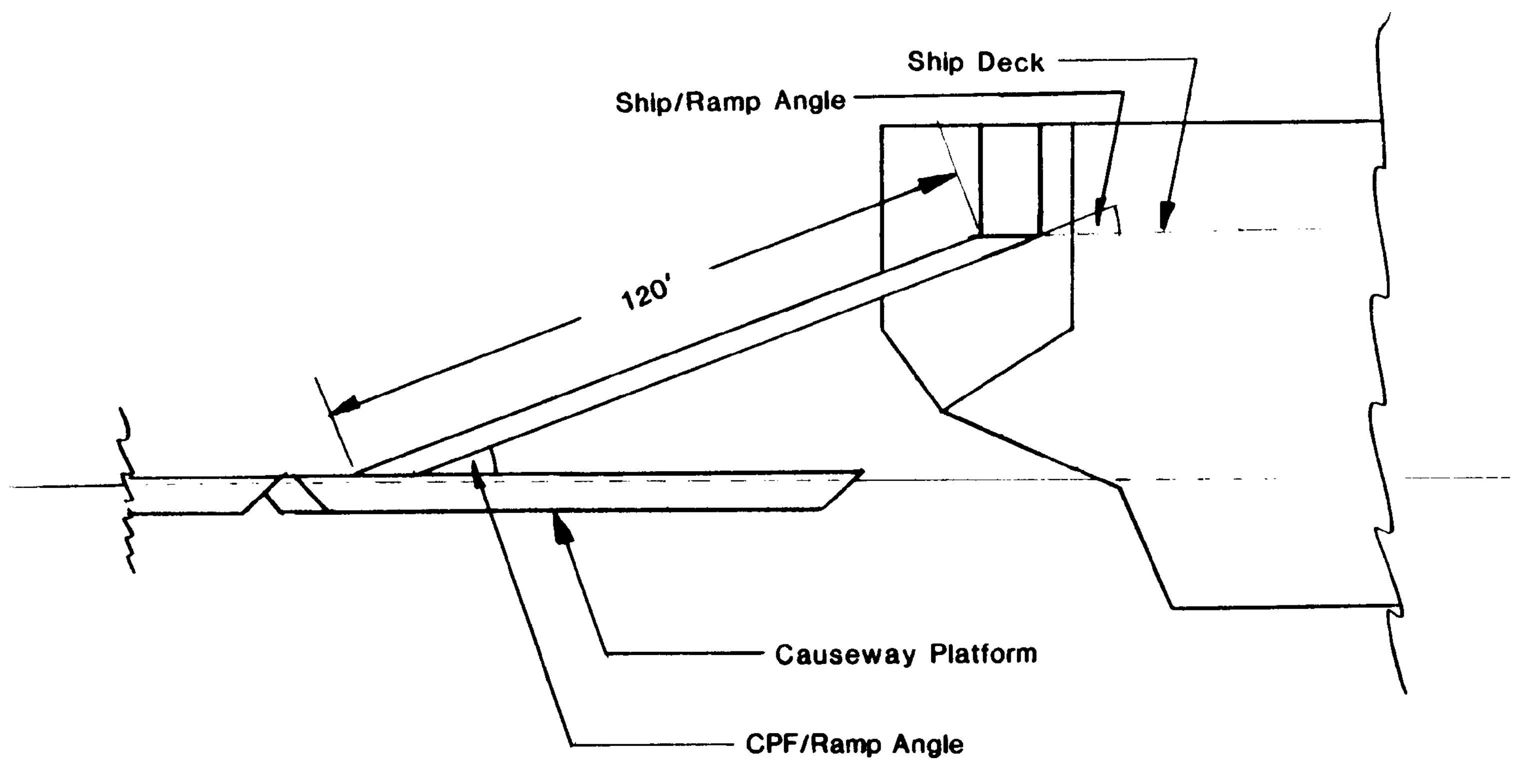
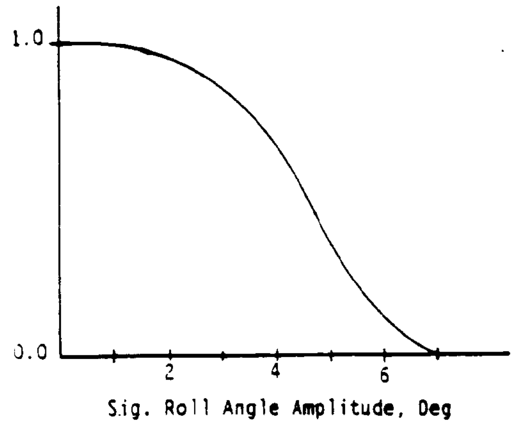
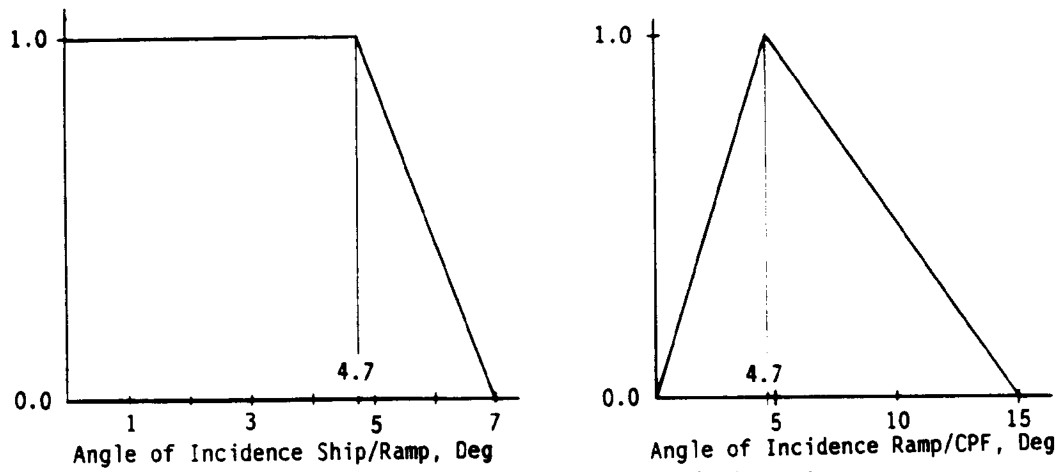


Figure 18 Assumed Ship/Ramp/CPF Geometry in Calm Water

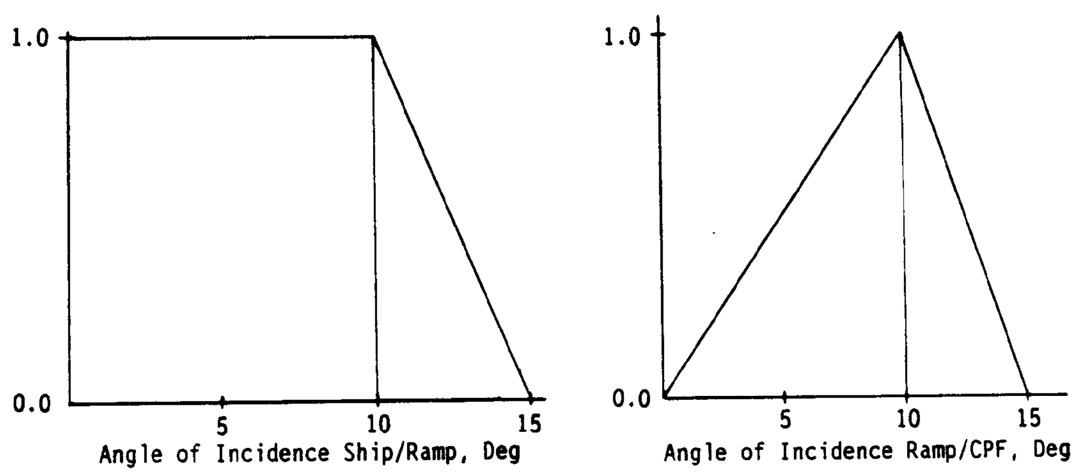
limit due to ramp torsional loads. There are two sets of utility curves for the ship/ramp and ramp/CPF angles. Figure 19 (b) illustrates those for the SS RO/RO vessels and Figure 19 (c) illustrates those for the NSS RO/RO vessels. For reasons mentioned above, these pairs of utility curves have a utility value of 1.0 at 4.7 degrees and 10 degrees, respectively. As shown in Figure 19 (b), for SS RO/RO vessels, a ship/ramp angle of incidence below 4.7 degrees is acceptable so the utility has a constant value of 1.0 in that range. The upper limit of this angle is 7.0 degrees, since at that point the bottom of the ramp would come in contact with the ship due to the hinge geometry. The utility curve therefore goes from 1.0 to 0.0 between 4.7 and 7.0 degrees, respectively. The upper limit of the ramp/CPF angle of incidence is 15 degrees, which is a function of typical vehicle geometry. The utility curve linearly decreases from 1.0 at 4.7 degrees to 0.0 at angles of 0.0 and 15.0 degrees. Figure 19 (c) illustrates the utility curves for NSS RO/RO vessels which were developed using the same logic. The differences are that the typical slope is 10 degrees and that the upper limit for the ship/ramp interface angle is 15 degrees which is determined from typical vehicle geometry.



a) Roll Angle Utility Curve



b) Utility Curves for SS RO/RO Vessels



c) Utility Curves for NSS RO/RO Vessels

Figure 19 Utility Curves Used in the Parametric Analysis

Table 5-2 lists the dimensionless values of all parameters used in this analysis. The motion related parameters were reduced using the previously illustrated utility curves. The other related parameters are also listed and a selected utility value is indicated.

TABLE 5-2
NON-DIMENSIONAL UTILITY VALUES
FOR PARAMETRIC ANALYSES
(scale of 0 to 1)

Parameter	Baseline CPF	Sealift CPF	Part. Art. CPF	10 Section CPF	NA Pontoon CPF
Ship/Ramp Angle (NSS RO/RO)	0.94	0.98	0.94	0.94	0.9
Ramp/CPF Angle (NSS RO/RO)	0.77	0.97	0.71	0.77	0.51
Roll Angle (NSS RO/RO)	1.0	1.0	1.0	1.0	1.0
Ship/Ramp Angle (SS RO/RO)	0.63	0.7	0.61	0.59	0.62
Ramp/CPF Angle (SS RO/RO)	0.53	0.71	0.47	0.53	0.46
Roll Angle (SS RO/RO)	0.9	0.92	0.89	0.9	0.97
Safety	0.7	0.9	0.6	0.7	0.6
RMA	0.8	0.7	0.8	0.8	0.8
Transportability	0.7	0.3	0.7	0.6	0.9
Time Req. (DEPLOY)	0.9	0.7	0.6	0.7	0.6
Pers. Req. (DEPLOY)	0.7	0.7	0.7	0.7	0.6
Time Req. (RET.)	0.8	0.7	0.8	0.8	0.8
Pers. Req. (RET.)	0.8	0.7	0.8	0.8	0.8
Pers. Req. (OPEN)	0.8	0.7	0.8	0.8	0.8

5.3 Ranking of Concepts

The overall scores for offloading capability in Sea State 3, as determined from the analysis previously described, are listed in Table 5-3. It is worth noting that cost has not been specifically addressed in this analysis at this point.

TABLE 5-3

PARAMETRIC ANALYSIS SCORES FOR CPF CONCEPTS

Concept	Score (Max. = 1.0)
Sealift Barge	0.78
Baseline CPF	0.769
10 Section CPF	0.738
Partially Articulated CPF	0.698
NA Pontoon CPF	0.694

Without comparing cost issues explicitly, the sealift barge scores slightly higher than the baseline CPF. The other three concepts do not fare as well and probably do not merit any further consideration. To compare the top two concepts in greater detail, it is instructive to consider the details of the input values of the analysis contained in Table 5-2. In the "hard" areas (i.e. the motion related parameters), the sealift barge scores well. In the "softer" areas, the scores for the sealift barge have been reduced using subjective rationale. A worthwhile exercise might be to develop a more detailed analysis of these issues. This would help to solidify the resulting conclusions and would be meaningful for future decisions. It is also worth noting that the roll damped concept is not contained in this final ranking, yet it still deserves further consideration.

6.0 SHIP-TO-SHORE ISSUES

In the analysis of conceptual solutions for Sea State 3 RRDF operability it is necessary to consider the problems associated with transferring vehicles to the beach after offloading from the ship to the RRDF to the transporting lighterage. The problems that are associated with the ship-to-shore transfer are independent of the concept chosen for the RRDF. The transfer process can be logically divided into three phases: connecting the lighterage to the RRDF, transitting to the beach, and crossing the surf zone.

6.1 Connection of Lighterage to the RRDF

The lighterage used in the process of ferrying cargo ashore is either the causeway ferry or an LCU. Each mode of transportation has its own set of relevant issues.

When the causeway ferry is used an extra causeway section ("B" section) in addition to the standard 3 x 2 arrangement is desirable and recommended. This extra section protrudes from the CPF and serves a very useful purpose for guidance and mooring of the causeway ferry. A side loadable warping tug, or a separate winch installed on the CPF, is recommended to use a bridle to moor the causeway ferry to the CPF. This provides a positive power source to guide the flexors into the receivers. Passing the bridle ends can easily be done from the "B" section. Connection of the bridle to the ferry flexors is dangerous since it requires someone to hang over the end of the causeway ferry. A pendant that remains on the end of the flexor and allows the connection to be accomplished on deck could help to alleviate this problem.

The LCU as a lighterage vehicle has its own unique problems in the connection to the CPF. One of the most significant is that it is extremely difficult and time consuming to connect the bow ramp of the LCU to the "rhino" horn on the CPF in Sea State 2 or higher. This problem will certainly be exacerbated in a higher sea state. There are three conceptual solutions to this problem that could be explored. A ramp from the CPF to the stern has been developed which should make the connection process easier by having more positive control of the ramp. The LCU is backed in alongside the "B" section and moored prior to lowering the ramp to its stern rhino horn. A "well-deck" concept causeway section could be developed which would allow the LCU to enter the protected well-deck for loading cargo. This section could be permanent in its configuration or ballasted to adjust as required. An extension of this concept would be to use other causeway sections to create a "harbor" for the LCU. It is not likely that this "harbor" would be as effective as having a "well-deck" section.

6.2 Transit to the Beach

Since the LCU is easily capable of transitting in Sea State 3, solutions to this portion of the problem should focus mainly on the causeway ferry. A powered causeway section would be used along with two or three other standard sections to make-up a standard ferry. The single biggest obstacle encountered during the transit of the causeway ferry is deck wetness. This can be either in the form of spray or green water on deck. The magnitude of the problem certainly depends on the severity of the environmental conditions.

Green water is usually defined as occurring when an actual wave washes over the deck. This can obviously be hazardous to personnel on deck and any loosely stowed cargo. Green water on deck would occur if a fully laden causeway ferry with minimum freeboard was operated in a severe environment. One simple way to reduce the amount of green water experienced is to not fully load the ferry which would increase the freeboard. This would have to be balanced against reduced throughput which would result.

The other aspect of the deck wetness problem is due to spray. This is usually generated by the causeway ferry "punching" through the seas or when waves from off the bow crash into the wall-sided freeboard of the causeway section and the resulting spray is blown over the deck. This problem can be particulary acute if the weather conditions are cold enough so that ice is formed on the decks or on the cargo. The problem of icing on the cargo is not severe, however, icing on deck can be very treacherous for personnel onboard.

Conceptual solutions of the deck wetness problem must either be directed toward reducing the relative motion between the causeway ferry and the wave surface or modifying the above-water structure to deflect the waves or spray. The only potential way to attempt to alter the motion of the causeway ferry (without changing the underwater geometry of the individual sections which make up the ferry) would be to add more sections to the ferry. In this way it might be possible to place the cargo in the center of a larger ferry in the hope of providing a somewhat drier environment. A potential solution to the above water geometry modification would be to develop some sort of deployable bulwark that would be fitted onto the causeway ferry in the field. In this way it would not effect the transportability of the individual sections.

The baseline causeway ferry and two wider variants were analyzed in a Sea State 3 Bretschneider Spectrum to determine whether this concept was worthwhile. Figure 20 illustrates the configurations of these variants. The "structure" numbers are indicated for reference in interpreting the calculated motions. Although the analysis only considered the ferry in head seas without any forward speed, the results are applicable to following seas and are still meaningful since the forward speed of the ferry is so low that the resulting effect on the wave-induced motions would be negligible. The significant motions of each structure and the likelihood of deck wetness at the leading edge of the ferry were calculated for each variant.

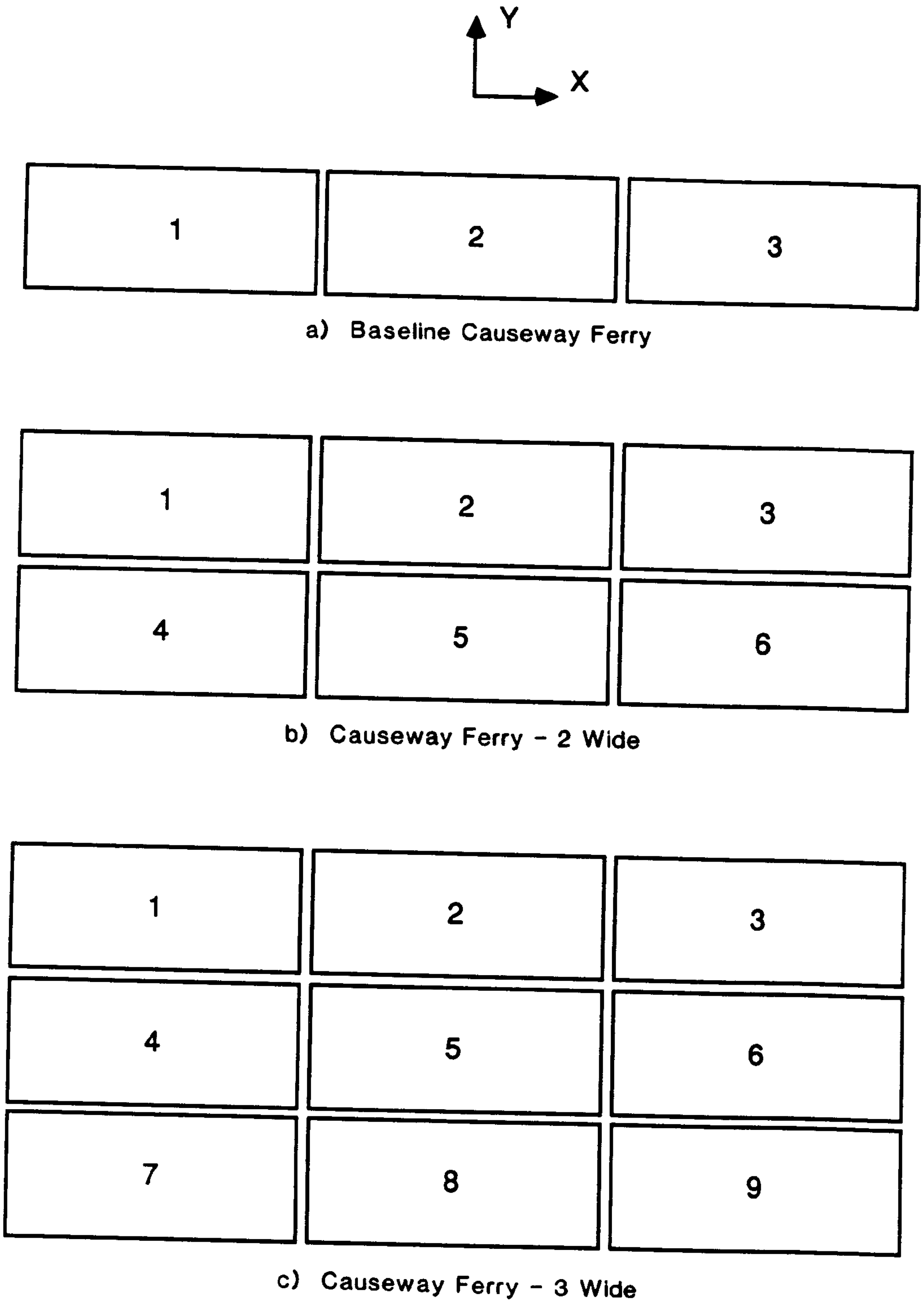


Figure 20 Causeway Ferry Options Analyzed

Table 6-1 lists the summary of the significant motions of the various causeway ferry concepts. It is clear from these results that in heave and pitch there is negligible difference between each variant. The only noticeable difference between the variations is in the roll motion. By adding more sections across, roll motion is induced in the center section. This is the same phenomenon that was observed in the previous analysis of the CPF. The observation is that by making a compliant structure larger, some of the motions can actually be degraded. Certainly this would not be the case if a rigid body were made larger.

TABLE 6-1

Summary of Causeway Ferry Motions
Head Seas, Bretschneider Spectrum
Sea State 3

	1 x 3 Causeway Ferry (Structure 3)	2 x 3 Causeway Ferry (Structure 3)	3 x 3 Causeway Ferry (Structure 3)	3 x 3 Causeway Ferry (Structure 6)
Significant Heave (FT)	0.7	0.8	0.8	0.6
Significant Pitch (DEG)	2.0	2.0	2.0	2.0
Significant Roll (DEG)	0.0	3.2	3.6	1.5

The likelihood of deck wetness being a problem was examined in the same manner as in the previous analysis of the CPF concepts. The cumulative probability of the occurrence of the local freeboard being less than 75% of the still-water freeboard was examined as a relative measure of merit. For the three variations studied, this cumulative probability at the leading edge of the ferry was essentially equal. There was a slight difference measured (on the order of 2%) but this is considered to be negligible and within the accuracy of the calculations.

Other potential transit concepts would be to use air cushioned vehicles or high-speed planing craft. This could be accomplished through the use of the LCAC or the Pontoon Air Cushion Kit (PACK), which is currently under development by the Army. The PACK is meant to convert a causeway section into an air cushioned vehicle. It is now under development for use with the modular causeways and could potentially be modified for use with the existing causeway sections. The PACK provides a much higher freeboard since the air cushion extends above the deck. High speed planing craft have been developed and could be considered.

6.3 Crossing the Surf Zone

In dealing with this portion of the transit, there is an obvious problem with breaking waves at the beach. The "surf zone" is generally defined as the region inshore of the position where the waves just start to break. The type of breaking wave experienced is dependent upon the deep water wave period, the deep water wave height, and the beach steepness. Generally, breaking waves are classified into four types: spilling, plunging, collapsing, and surging.

There are no validated analytical methods for dealing with the surf zone. Some models of wave velocities have been generated but relating them to floating bodies has not been validated. Experimental evaluation is typically utilized for studying this region.

The problems associated with crossing the surf zone can be related to the size of the vehicle. In the case of smaller vessels, broaching can occur if the vessel lacks suitable power for positive control. Depending on the beach steepness, it is conceivable that a causeway ferry could land on the beach and fully extend beyond the surf zone. On a gradually sloped beach this would not be the case however and having a compliant structure such as the causeway ferry fully within the surf zone will result in an unacceptable situation.

A potential solution could be to use the Elevated Causeway with the Calm Water Ramp to an additional floating platform extending beyond the surf zone. However, a solution such as this would require more assets.

Other potential solutions would require lighterage other than the Causeway Ferry. Air cushioned vehicles including a PACK equipped causeway could "fly" onto the beach. Planing craft could be used for ferrying cargo and landing on the beach. Craft such as these should be able to navigate through the surf but would have a more limited payload.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The analysis of conceptual solutions for solving the Sea State 3 RRDF operability problems leads to the following conclusion:

- The baseline CPF's motions in Sea State 2 have been proven to be acceptable and are established as target values for new concepts to meet in Sea State 3.
- The sealift barge is the only concept that meets this target.
- The analytical study of the effect of external roll dampers on the CPF motions has proven inconclusive. Physical experiments, either in model scale or in prototype form, should be conducted in order to completely evaluate the merit of this concept.
- The results of the parametric analysis, which did not include the roll-damped concept because of the inconclusive nature of the analytical studies, indicate that the sealift barge and the baseline CPF rank very close to each other. Some subjective rationale was utilized in the "soft" areas of this analysis (i.e. cost, RMA, etc.) Further quantification of these parameters is recommended to clarify the relative value of each configuration.
- The causeway ferry is a useful form of lighterage in that the capability to carry large loads exists. Its limitations are due to deck wetness in a seaway and perhaps transitting the surf zone on certain beach topographies. Increasing the number of sections to widen the ferry is not likely to improve the motions.
- The PACK appears to be a promising solution for dealing with ship-to-shore problems in transit and at the beach.
- High speed lighterage, with a smaller payload capacity, would have few ship-to-shore transit problems and the mission effectiveness of these

should be evaluated.

Recommendations for future work include:

- o Experimentally evaluate the external roll dampers for the CPF. This should be accomplished in two phases. Damping coefficients for simple dampers of various geometries should be measured. These coefficients can then be utilized in the analytical model. Further model experiments with roll dampers installed on the CPF should be conducted to account for any additional interference effects between the CPF and the dampers.
- o The Sealift Barge concept should be evaluated during the conduct of an exercise. This would help to clarify the value of this concept.
- o ELCAS to CPF tests at the beach should be conducted during an exercise to evaluate this as a solution to problems associated with transit at the beach.
- o The PACK should be evaluated for the modification of NL Pontoon causeway sections.

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